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Evaluation of Various Anatomical Features in Human Mandibular and Maxillary Molar Roots in the Northern Anatolian Population

Kuzey Anadolu Populasyonunda İnsan Mandibular Molar Köklerinin Çeşitli Anatomik Özelliklerinin Değerlendirilmesi

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This study was presented as a poster in ESE European Endodontology Association Biennial Congress (12-14.09.2013) and 17th Biennial ESE Congress (16-19.09.2015) in Barcelona, Spain.

ABSTRACT Objective: To examine the root apical morphology of human maxillary and mandibular first and second molars in the northern Anatolian population. **Material and Methods:** A total of 2140 human maxillary and mandibular first and second molars were investigated using a computer-aided stereomicroscope with 80X magnification. The following observations were made: count of apical foramina, the shape and the widest and the narrowest diameters of apical foramina, accessory foramina frequency, the location of apical foramina on the root surface and the distance between the anatomical apex and apical foramina. **Results:** The most frequently observed shape among the minor apical foramina was oval. Both maxillary and mandibular molar roots had a maximum of two minor apical foramina. The mean narrowest and widest diameters of the apical foramina of all roots of maxillary molars ranged from 186.77 to 364.79 µm and 223.98 to 453.42 µm, respectively. The mean narrowest and widest diameters of the apical foramina of all roots of mandibular molars ranged from 178.79 to 309.20 µm and 209.79 to 419.55 µm, respectively. Frequency of accessory foramina ranged between 2.5% and 53.33% for the roots of maxillary molars, whereas the frequencies ranged from 14.29% to 44.12% for the roots of mandibular molars. The mean distance between the anatomical apex and apical foramina ranged from 357.88 to 626.391 µm for the roots of maxillary molars, while it ranged from 392.69 to 1126.36 µm for mandibular molars. **Conclusion:** The results of this study revealed that anatomic features of the root apical region are highly complex among the investigated population.

Keywords: Apical foramen; anatomy; molar; tooth apex; tooth root

ÖZET Amaç: Kuzey Anadolu popülasyonunda insan maksillar ve mandibular birinci ve ikinci molar dişlerin apikal kök morfolojisinin incelenmesidir. **Gereç ve Yöntemler:** Toplam 2140 maksillar ve mandibular birinci ve ikinci insan molar dişi 80X büyütmede bilgisayar destekli stereomikroskop kullanılarak incelendi. Takip eden gözlemler yapıldı: apikal foramenin sayısı, apikal foramenlerin en geniş ve en dar çapları ile şekli, aksesuar foramen sıklığı, apikal foramenin kök yüzeyindeki yeri ve anatomik apeks ile apikal foramen arası uzaklık. **Bulgular:** En sık gözlenen apikal foramen şekli ovaldi. Maksillar ve mandibular molar köklerin her ikisinde de en fazla 2 apikal foramen tespit edildi. Maksillar molar dişlerin tüm köklerindeki apikal foramenlerin ortalama en dar ve en geniş çapları sırasıyla 186,77 ila 364,79 µm ve 223,98 ila 453,42 µm aralığında bulundu. Mandibular molar dişlerin tüm köklerindeki apikal foramenlerin ortalama en dar ve en geniş çapları sırasıyla 178,79 ila 309,20 µm ve 209,79 ila 419,55 µm, aralığında bulundu. Aksesuar foramen sıklığı maksillar molarların köklerinde %2,5 ila %53,33 aralığında bulunmakta iken mandibular moların köklerinde %14,29 ila %44,12 aralığında bulunmuştur. Maksillar molar diş köklerinde anatomik apeks ile apikal foramen arası uzaklık 357,88-626,391 µm aralığında bulunduğu belirlenmiş iken mandibular molar köklerinde 392,69-1126,36 µm aralığında bulunmuştur. **Sonuç:** Bu çalışmanın yürütüldüğü popülasyonda kök apikal bölgesinin anatomik özelliklerinin ileri seviyede komplekslik gösterdiği görülmüştür.

Anahtar Kelimeler: Apikal foramen; anatomi; azı dişi; diş apeksi; diş kökü

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Success in endodontic treatment depends on elimination of tissue remnants, disinfection of entire root canal system, and then effective sealing of the root canal system to prevent reinfection.[1] However, various pathogens could survive from endodontic disinfection process by hiding in the anatomic intricacies such as lateral canals, ramifications, isthmuses, accessory canals.[2] Besides, preoperative size of apical foramina and as well as the shape of apical foramina have directly affect the estimating of final preparation size to achieve adequate disinfection and shaping of apical foramen.[3] Therefore, non-surgical endodontic treatment steps such as determining working length and estimating initial size of the apical foramen are required to gain accurate tooth anatomy knowledge.[4] On the other hand, these anatomic features on the apical third of the root would cause failure of non-surgical endodontic treatment even strictly obeying non-surgical endodontic treatment procedures, and surgical endodontic treatment would then become a treatment option.[3,5,6] So, these anatomical openings to root surface of root canal system should be well defined and should surgically eliminate to achieve surgical success.[7] Therefore, this study was conducted to improve anatomic knowledge for maxillary and mandibular molars in the northern Anatolian population.

Numerous researches have been conducted on dental anatomy by using several methods such as dye perfusion with subsequent demineralization, computer-aided stereomicroscope, histological sectioning, 3D imaging and micro-computed tomography.[4,8-12] Advanced technological methods such as 3D imaging or micro-computed tomography can provide more accurate measurements; however, these techniques require more time and more financial support than alternative methods, thus creating a challenge when working with a large data set of teeth.[10,11] Conversely, computer-aided stereomicroscopic analysis is simple to perform and can be easily used on a large number of teeth with high accuracy.[12]

Anatomic features such as maximum and minimum diameters of minor apical foramina, number of minor apical foramina, number of accessory foramina, shape of minor apical foramina, distance of minor apical foramina from the anatomical apex, locations of apical foramina all directly impact the success of surgical or non-surgical root canal treatments.[4,12] Previous studies revealed that anatomic features of teeth would be varied among the different populations.[4,12,13] Still, there are limited publications on these anatomic features regarding the Turkish population, especially with respect to the location of apical foramina.

The aim of this study is to investigate the various anatomic features that is, the maximum and minimum diameters of minor apical foramina, number of minor apical foramina, number of accessory foramina, shape of minor apical foramina, distance of minor apical foramina from the anatomical apex and locations of apical foramina on the root surface in a Turkish population that lives in the northern region of Anatolia.

MATERIAL AND METHODS

This study was performed in accordance with the World Medical Association Declaration of Helsinki (2008). Permanent human maxillary and mandibular first and second molar teeth that were discarded by their owners after extraction were collected daily from various private and public dental clinics at the region in which this study was performed. Teeth that had a fractured or resorbed root or teeth that had been previously treated by root canal were excluded immediately, and the soft tissue remnants and calcified remnants on the remaining teeth were removed and stored in distilled water. A total of 2140 extracted maxillary and mandibular human teeth were selected. Then, soft tissue remnants around and in the foramen area were removed using a size 6 K file (Dentsply Maillefer, Ballaigues, Switzerland) at 40X magnification (Nikon SMZ 1500 stereo microscope, Nikon Co., Japan). The roots were submerged into ink and then washed under running tab water. Afterwards, they were dried with pressurized air before examination to ensure more accurate determination of apical foramina. The anatomical apex, which is the most apical point of the root, was marked with a red dot by using a fine tipped CD marker. The apical foramen was defined as the opening of the root canal on the

external root surface. The outermost diameter of the apical foramen was termed as the major apical foramen, and the minor apical foramen was considered to be the narrowest planer dimension of the apical foramen.[4,12]

The crown of the tooth was embedded into a bulk of playdough, which was placed into a plastic cup so that the apical part of the roots could be easily oriented to the objective lens of the stereomicroscope by mild finger movements. The major apical foramen of each root was oriented parallel to the objective lens, and then the objective lens was focused on the minor apical foramen. Afterwards, the measurements were performed using the digital sight system and its software.

A computer-aided stereomicroscope (Nikon SMZ 1500) with 80X magnification was used to examine the samples. A cold light source (Photonic PL 2000, Photonic Optische Geräte GmbH & Co KG; Austria) illuminated the samples during the examinations. The measurements were performed using a digital sight system (Nikon digital sight DS-L1, Nikon Co., Japan), which was calibrated using a micro scale (in micrometers).

The maximum and minimum diameters of the minor apical foramina, number of minor apical foramina, number of accessory foramina, shape of the minor apical foramina, the distance between minor apical foramina and the anatomic apex, locations of apical foramina on root surface and frequency of accessory foramina were investigated as described below.

MAXIMUM AND MINIMUM DIAMETERS OF MINOR APICAL FORAMEN

The widest and narrowest diameters of every apical foramen were measured using the digital sight system of the stereomicroscope, and foramina with diameters greater than 100 µm were considered as the main apical foramen. However, if all of the apical foramina on the root apex were narrower than 100 µm, the widest foramen of them was considered as the main foramen in this study (Figure 1).

NUMBER OF MINOR APICAL FORAMINA

All root surfaces were investigated carefully to detect all foramina, and then all detected foramina were measured with 80X magnification. The investigated foramina, which have diameters greater than 100 µm, were considered as minor apical foramina, and then the quantity of the minor apical foramina was recorded (Figure 2).

NUMBER OF ACCESSORY FORAMINA

If all foramina diameters were narrower than 100 µm, they were considered accessory foramina. However, if all the foramina on the root had diameters less than 100 µm, the widest foramen was considered as the minor apical foramen.

SHAPE OF MINOR APICAL FORAMEN

The round and the oval shape terms were defined according to the study of Marroquin et al.[12] If the difference between the maximum and minimum diameters of the minor foramen was greater than 20 µm, it was considered to have an oval shape, whereas,

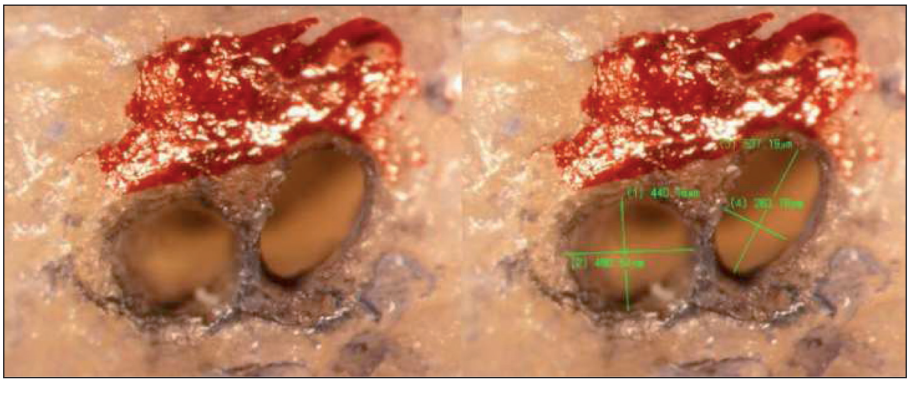

FIGURE 1: Measuring of the diameters of the apical foramina.

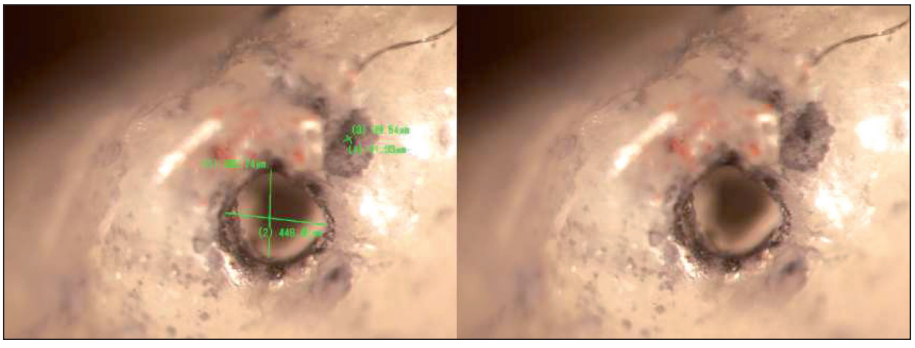

FIGURE 2: Measuring of the diameters of an apical foramen and a accessory foramen (Mandibular first molar, distal root).

FIGURE 3: Irregular shaped minor apical foramen.

FIGURE 4: Measuring of the distance of minor apical foramina from the anatomical apex.

if it was smaller than 20 µm, it was defined as a round shape. Triangular, kidney or any other kind of other shapes were classified as irregular. Therefore, shapes of minor apical foramina were classified as oval, round or irregular (Figure 3).

DISTANCE BETWEEN MINOR APICAL FORAMINA AND THE ANATOMICAL APEX

To measure the distance between the minor apical foramina and the anatomical apex, each foramen was separately focused parallel to the objective lens. Then, a straight line was drawn parallel to the root from the tip of the anatomical apex to the center of the minor apical foramina on the image of the root via the measure mode of the digital sight system of the stereomicroscope system. The length of this line was recorded as the distance between the minor apical foramen and the anatomical apex (Figure 4).

LOCATION OF APICAL FORAMINA ON THE ROOT SURFACE

The location of the apical foramina on the root surface was recorded as mesial, distal, apical, buccal and palatinal or lingual.

RESULTS

Seven hundred and eighty maxillary first molars (2480 apical foramina), 440 maxillary second molars (1660 apical foramina), 460 mandibular first molars (1420 apical foramina) and 460 mandibular second molars (1540 apical foramina) were investigated in this study, and the obtained measurements are presented in Table 1, Table 2 and Table 3.

MAXIMUM AND MINIMUM DIAMETERS OF MINOR APICAL FORAMINA

The mean width of the narrow and wide diameters of the minor apical foramina of maxillary first and second molars ranged from 164.63 μm to 364.79 μm and 223.98 μm to 453.42 μm, respectively. The mean width of the narrow and wide diameters of the minor apical foramina of mandibular first and second molars ranged from 178.09 to 309.20 μm and 209.79 to

TABLE 1: Anatomic features of maxillary molars.

Maxillary Molars									
			MB	MB1	MB2	DB	P	P1	P2
Frequency of accessory foramina (%)	First molar	0	72.73	50.0	54.55	66.67	60.61	60.67	70.0
		1	13.64	40.91	40.91	18.18	30.30	25.0	20.0
		2	9.09	9.09	4.55	12.12	9.09	8.33	10.0
		3	4.54	—	—	3.03	—	—	—
		n	220	440	440	660	600	60	60
	Second molar	0	71.43	53.33	46.67	86.36	75.0	97.5	95.0
		1	25.0	40.0	33.33	9.09	15.0	2.5	5.0
		2	—	6.67	6.67	4.55	10.0	—	—
		3	3.57	—	13.33	—	—	—	—
		n	140	300	300	440	600	40	40
The distance between minor apical foramina and anatomical apex (μm)	First molar	Mean	533.6	553.2	1090.4	354.0	357.9	435.50	1278.6
		Maximum	1746.1	1452.7	3229.2	1188.0	1286.7	1306.6	1738.0
		Minimum	0	0	0	0	0	0	682.47
		SD	303.72	245.36	551.18	169.52	297.7	354.38	540.89
	Second molar	Mean	626.39	568.7	1235.44	339.09	388.54	748.97	1920.97
		Maximum	1386.37	1107.3	3496.18	1033.48	1490.08	1202.76	2327.91
		Minimum	0	0	0	0	0	0	1202.76
		SD	304.73	377.4	858.12	165.67	291.55	543.46	623.83
Location of minor apical foramina on root surfaces	First molar	Bs	2.27	4.55	4.55	15.15	6.67	6.67	1.67
		Ps	25.0	4.55	31.82	6.06	13.34	16.67	66.6
		Ms	4.55	18.18	22.73	3.03	3.34	3.33	13.33
		Ds	34.09	31.82	9.09	24.24	20.00	20.0	15.0
		As	34.09	40.91	31.82	51.52	56.67	53.33	3.33
		n	220	440	440	660	600	60	60
	Second molar	Bs	—	26.67	—	4.55	10.53	2.5	7.5
		Ps	14.29	6.67	20.0	—	5.26	17.5	45.0
		Ms	28.57	13.33	13.33	9.09	5.26	10.0	12.5
		Ds	14.29	33.33	46.67	31.82	15.79	32.5	5.0
		As	42.86	20.0	20.0	54.55	63.16	37.5	30.0
		n	140	300	300	440	400	40	40
Shape of minor apical foramina (%)	First molar	Oval	63.64	68.18	60.23	60.91	70.67	71.67	78.33
		Round	22.78	27.27	34.09	36.21	23.83	16.67	11.67
		Irregular	13.64	4.55	5.68	2.88	5.5	11.67	10
		n	220	440	440	660	600	60	60
	Second molar	Oval	66.43	61.0	72.0	62.05	70.0	80.0	77.5
		Round	22.14	34.0	25.0	35.0	25.0	15.0	15.0
		Irregular	11.43	5.0	3.0	2.73	5	5.0	7.5
		n	140	300	300	440	400	40	40

MB, presence of single foramen at mesial root; MB1 and MB2, presence of two separate foramina at mesiobuccal root; DB; presence of single foramen at distal root; P, presence of single foramen at palatinal root; P1 and P2, presence of two separate foramina at palatinal root; Bs, buccal surface; Ls, lingual surface; Ms, mesial surface; Ds, distal surface; As, apical surface.

TABLE 2: Anatomic features of mandibular molars.

			Mandibular Molar					
			M	MB	ML	D	DB	DL
Frequency of accessory foramina (%)	First Molar	0	83.33	61.76	55.88	78.57	75.0	62.50
		1	16.67	35.29	41.18	14.29	25.0	37.50
		2	—	2.94	11.76	7.14	—	—
		3	—	—	—	—	—	—
		n	120	340	340	300	160	160
	Second Molar	0	85.71	68.75	62.5	66.67	85.71	73.33
		1	14.29	25.0	18.75	22.22	7.86	13.33
		2	—	6.25	12.5	11.11	6.43	9.67
		3	—	—	6.25	—	—	3.67
		n	140	320	320	180	280	280
The distance between minor apical foramina and anatomical apex (µm)	First Molar	Mean	803.07	697.76	974.02	675.62	634.14	952.54
		Maximum	1817.07	1627.0	2949.0	1761.3	1233.36	2265.14
		Minimum	0	0	0	0	0	0
		SD	445.39	367.37	612.86	415.9	357.1	627.67
	Second Molar	Mean	392.69	437.09	1126.04	400.39	316.74	664.26
		Maximum	921.51	1316.32	2628.25	1651.0	939.22	1565.26
		Minimum	0	0	0	0	0	0
		SD	258.26	323.47	646.21	231.59	267.17	375.90
Location of minor apical foramina on root surfaces (%)	First Molar	Bs	58.33	5.88	17.65	20.0	4.38	2.5
		Ls	4.17	11.76	5.88	6.67	12.5	12.5
		Ms	1.67	0.88	5.88	6.67	1.88	1.25
		Ds	10.83	40.59	35.29	26.67	25	35.63
		As	25.0	40.88	35.29	40	56.25	48.13
		n	120	340	340	300	160	160
	Second Molar	Bs	28.57	17.81	9.38	4.44	3.93	2.14
		Ls	5.0	1.88	3.13	6.67	7.14	9.64
		Ms	10.0	0.94	25.0	11.11	3.21	6.07
		Ds	13.57	30.31	30.94	31.67	21.43	39.29
		As	42.86	49.06	31.56	46.11	64.29	42.86
		n	140	320	320	180	280	280
Shape of minor apical foramina (%)	First Molar	Oval	57.5	56.25	61.25	53.33	50.0	62.5
		Round	38.33	37.5	36.56	33.33	37.5	33.75
		Irregular	4.17	6.25	2.19	13.33	12.5	3.75
		n	120	340	340	300	160	160
	Second Molar	Oval	71.43	61.88	68.75	54.44	43.21	47.50
		Round	24.29	36.56	27.5	43.33	50.36	49.64
		Irregular	4.29	1.56	3.75	2.22	6.43	2.86
		n	140	320	320	180	280	280

M: presence of single foramen at mesial root; MB and ML: presence of two separate foramina at mesial root; D: presence of single foramen at distal root; DB and DL: presence of separate foramina at distal root; n: sample count; Bs: buccal surface; Ls: lingual surface; Ms: mesial surface; Ds: distal surface; As: apical surface.

419.55 µm, respectively (Table 3). According to the results of this study, if a root of any molar tooth has a single apical foramen, this foramen usually has a wider diameter than a root that has two minor apical foramina (Table 3).

NUMBER OF MINOR APICAL FORAMINA

The results of this study showed that the distal roots of the first and second maxillary molars always have a single foramen. Other roots of maxillary first and second molars and all the roots of mandibular first and second molars had either a single foramen or at maximum two apical foramina. The frequency of having a single foramen was 32.35% for maxillary first molar and 54.55% for maxillary second molar. The single-foramen frequency of the palatinal roots of maxillary first molars was 91.18%, whereas it was 90.91% for second molars. Mandibular first molars had a frequency of 26.06% of having a single foramen in mesial roots, whereas 65.22% had a single foramen in distal

TABLE 3: Mean maximum and minimum diameter of molars (µm).

			MB		MB1		MB2		DB		P		P1		P2	
			Narrow	Wide	Narrow	Wide	Narrow	Wide	Narrow	Wide	Narrow	Wide	Narrow	Wide	Narrow	Wide
Minimum and maximum diameter of minor apical foramina (µm)	Maxillary First Molar	Mean	207.15	291.24	188.30	277.77	164.63	223.98	208.14	270.73	292.2	383.0	364.79	453.42	241.3	397.11
		Maximum	339.19	561.20	332.85	539.89	315.53	344.74	416.06	592.32	766.06	895.16	397.42	485.90	281.05	565.1
		Minimum	72.68	80.1	83.27	86.27	51.89	90.47	62.89	87.97	105.7	152.35	324.16	430.89	197.47	307.52
		SD	71.03	101.55	59.53	102.94	77.1	92.07	84.86	102.55	138.44	188.72	37.28	28.82	41.94	145.59
	Maxillary Second Molar	Mean	212.38	301.48	217.38	295.63	186.77	244.73	197.94	244.73	305.40	398.25	228.03	244.36	198.76	295.91
		Maximum	298.45	411.75	393.83	564.02	440.75	532.83	394.19	532.83	459.94	627.47	242.73	244.64	226.06	345.44
		Minimum	51.11	197.66	58.52	73.31	92.78	165.45	48.86	135.45	166.57	182.31	213.32	244.07	171.45	246.37
		SD	88.14	71.89	102.11	157.81	85.38	89.97	82.65	89.97	90.67	118.39	20.80	0.4	38.62	70.05
			M		MB		ML		D		DB		DL			
			Narrow		Wide	Narrow	Wide	Narrow	Wide	Narrow	Wide	Narrow	Wide	Narrow		Wide	
	Maxillary First Molar	Mean	282.86		382.48	210.65	257.35	178.09	209.79	309.2	419.55	199.82	243.64	182.41		245.27	
		Maximum	394.53		731.69	320.74	367.39	281.68	332.03	570.93	653.29	475.21	553.86	328.5		353.0	
		Minimum	118.61		229.27	94.74	155.23	58.26	86.79	133.97	150.09	62.89	87.97	64.48		164.85	
		SD	111.26		186.13	66.07	62.63	70.12	82.53	118.40	166.31	146.91	149.66	97.24		74.7	
	Maxillary Second Molar	Mean	197.67		364.33	217.94	285.24	217.73	283.74	254.63	379.95	178.79	250.93	246.96		341.48	
		Maximum	312.65		537.8	393.83	564.02	440.73	532.83	377.21	618.07	302.49	645.38	428.85		627.47	
		Minimum	51.11		265.29	42.96	66.66	98.14	114.9	148.86	197.73	73.52	93.93	99.91		123.04	
		SD	99.46		104.15	95.84	133.05	90.55	104.86	85.61	127.24	80.91	155.44	92.11		123.76	

For maxillary molars: MB: presence of single foramen at mesial root; MB1 and MB2, presence of two separate foramina at mesiobuccal root; DB: presence of single foramen at distal root; P: presence of single foramen at palatinal root; P1 and P2, presence of two separate foramina at palatinal root for mandibular molars: M, presence of single foramen at mesial root; MB and ML, presence of two separate foramina at mesial root; D: presence of single foramen at distal root; DB and DL, presence of two separate foramina at distal root SD, standard deviation

roots. On the other hand, 69.57% of mandibular second molars exhibited a single foramen in mesial roots, while 60.87% had a single foramen in distal roots.

NUMBER OF ACCESSORY FORAMINA

A maximum of 3 accessory foramina were found on the investigated roots in this study. The frequency of accessory foramina varied from 2.5% to 53.33% for maxillary molars, whereas the frequency of accessory foramina ranged from 2.94% to 41.18% for mandibular first and second molars (Table 1 and Table 2).

SHAPE OF MINOR APICAL FORAMEN

The most common minor foramen shape was oval for all molar teeth groups. Round-shaped apical foramina were only observed more frequently than the others at the distal roots of mandibular roots if they had 2 apical foramina (50.36% of DB and 49.64% of DL). Irregular minor apical shape was the most rarely seen shape for all of the investigated teeth. Its frequency ranged from 1.56% to 6.43% in mandibular teeth, while it ranged from 2.73% to 13.64% in maxillary teeth (Table 1 and Table 2).

DISTANCE OF MINOR APICAL FORAMINA FROM THE ANATOMICAL APEX

The distance between the anatomical apex and the minor apical foramina of the investigated teeth ranged from 0 to 3496.18 µm. The mean distance ranged from 357.88 µm to 626.39 µm for maxillary molar roots, while the mean distance of mandibular molar roots ranged from 392.69 µm to 1126.36 µm (Table 1, Table 2).

LOCATION OF APICAL FORAMINA ON THE ROOT SURFACE

Locations of apical foramina rates are listed in Table 1 and Table 2. According to the data obtained from this study, minor apical foramina could be opened from every surface of root; however, the openings were dominantly located on the apical and distal surfaces of roots for all groups (Table 1, Table 2).

DISCUSSION

Anatomical studies on teeth can use various techniques such as histological examinations, computer-aided stereomicroscopy, scanning electron microscopy, three-dimensional imaging, high-resolution tomography or micro tomography.[4,8-12] Computer-aided digital stereo microscopy with an integrated software analysis method, which was used in this study, has various advantages for example, it is easy to use and requires less equipment and financial burden. Therefore, a large number of samples could easily be investigated with high accuracy by using this method.[11,12]

NUMBER OF MINOR APICAL FORAMINA

Sealing of all root canal systems is crucial to achieve success in root canal treatment.[1] If a root canal system is terminated with more than one minor apical foramen at the root apex, a clinician would fail to seal all minor apical foramina by non-surgical root canal treatment. For these cases, surgical endodontic approach becomes a treatment choice. Every opening of the root canal system must be located and sealed with retrograde filling during the endodontic surgery.[7] Therefore, determining the number of minor apical foramina from molar roots was one of the aims of this study.

A maximum two minor apical foramina were found on the investigated maxillary and mandibular molar roots in this study. Similarly, Marraquin et al. found a maximum of two minor foramina in a population from Egypt.[12] On the other hand, the presence of more than two apical foramina was also reported in previous papers.[4,14] However, the frequencies of one and two apical foramina were high in these articles. These findings might be due to ramifications or splinting of canals in roots, or this might also indicate the presence of a third canal. Therefore, further researches about the relationships between root canal count and apical foramina count should be performed.

MAXIMUM AND MINIMUM DIAMETERS OF MINOR APICAL FORAMINA

Natural diameters of minor apical foramina have great importance to determine the final size of apical preparation. The master apical file should touch all of the walls of the minor apical foramen to establish a proper sealing of the root canal system to prevent any leakage into the root canal system.[4] According to

the study of Arora and Tewari, apical preparation should be terminated using an instrument four or five times larger than the initial file size to make all walls of the apical foramen touch the master apical file for 95% of the teeth.[4]

The mean size of minor apical foramina of the investigated molars in this study ranged from 178.09 to 453.42 µm, which is in accordance with the previous studies of Marraquin et al. (200-290 µm), Cheung, Yang and Fan (320 µm), Wu, Roris, Barkis and Wesselink (130-460 µm) and Arora and Tewari'nin (158-320 µm).[4,12,15,16] On the other hand, Ayranci et al. reported lower findings that ranged from 101 to 302 µm.[14] All of these studies used similar investigation methods; however, the findings of these studies are vastly different and have a high standard deviation. Therefore, these studies indicate that the anatomic features of the root apex could greatly differ, even in neighboring populations.[14] Finally, according to the results of this study, we recommend that the initial file size of every case should be estimated privately.

NUMBER OF ACCESSORY FORAMINA

Many studies considered foramina that were narrower than 0.10 mm as accessory foramina, and in these studies, the maximum number of accessory foramina was reported as six.[4,12,14] These studies also revealed that mesiobuccal roots have more accessory foramina compared to other roots. Previous studies on root canal anatomy showed that mesiobuccal roots of maxillary molars have a more complex root canal system than the other roots and that a high number of accessory foramina in the mesiobuccal root would be due to this reason.[13,15,17] In line with these reports, the accessory foramina frequency for the mesiobuccal root was dramatically increased in this study. The accessory foramina presence incidence of maxillary first and second molars ranged from 7.14% to 41.62%, whereas accessory foramina presence incidence for mandibular first and second molars in the study of Marraquin et al. ranged from 5.41% to 35.35% However, Arora and Tewari reported a 2-14% accessory foramina presence rate for maxillary molars and 4 to 14% for mandibular molars.[4,12] Ayrancı et al. reported an accessory foramina incidence rate between 21 and 42% for maxillary first and second molars and 26-43% for mandibular first and second molars.[14] This study revealed similar findings that is, 2.5-50% for maxillary molars and 14.29-44.12% for mandibular molars. Accessory foramina would indicate the presence of either an accessory canal or ramifications.[18] Clinicians should pay particular attention to irrigation and irrigation activation protocols or methods to ensure adequate disinfection of this part of the root canal system.

SHAPES OF MINOR APICAL FORAMINA

Minor apical foramina were found to be in various shapes. Authors defined the shape of each foramen as oval when the difference between the wide and narrow diameter of the apical foramen was equal or greater than 0.02 mm.[4,12] Previous studies revealed that the most common shape was oval followed by a round shape.[4,12] All other kinds of shapes (e.g., triangular, rectangular, kidney) were encountered less frequently and were defined as irregular.[4,12] The results of this study were in agreement with these authors. On the contrary, Martos et al. reported that a round-shaped foramen was the most common shape (52.90%) followed by oval (25.20%).[19] However, a different study method was used in this study, and the sample size of this shape was also very small in this study, so differences between these studies could be due to these reasons.

DISTANCE OF MINOR APICAL FORAMINA FROM THE ANATOMICAL APEX

Many authors noted that the minor apical foramen and the anatomical apex usually do not intersect.[4,12,14,20] However, the reported mean distance between the minor apical foramen and the radiological apex varied in these previous studies. Marroquin et al. reported mean distances of 640-1440 µm between the minor apical foramen and the anatomical apex for maxillary molars.[12] Arora and Tewari reported distances of 632-996 µm, which are close to results of Marroquin et al. On the contrary, Ayranci et al. reported much shorter distances (271-519 µm).[4,12,14] The results of the present study were close to Marraquin et al. and Arora and Tewari for maxillary molars (357.88-1920.97 µm) and mandibular mo-

lars (316.74-1126.04 µm).[4,12] Ayranci et al. also reported shorter mean distances for mandibular molars.[14] These differences may be due to the different measurement methods used, different apical foramen definitions or the difference between reference points used to measure distances. All of these results support the fact that the apical zone is highly complex around the world and even in neighboring populations. Nowadays, the recommended working length determination method depends on determining the working length using electronic apex locators and confirmation via radiography, and it seems that this recommendation will be valid in the near future.

LOCATION OF APICAL FORAMINA ON THE ROOT SURFACE

Radiography is an indispensable method used in dentistry and is currently used for determining working length. However, one of the important faults of determining working length with radiography is the image, which is taken in the bucco-lingual direction. Therefore, apical foramina that are located on the buccal or lingual aspect of the root would prevent accurate determinations of working length by using radiography. On the other hand, all apical foramina that are located on the buccal or lingual side of a root should be found and filled during root apex surgery. Therefore, the location of apical foramina on the root surface was also investigated in this study.

Many of the previous studies reported the location of apical foramina as "at lateral" or "at apical", and the common findings of these studies were that the apical foramina are usually located at lateral aspects of the dental root.[13,17,18,21] On the other hand, Martos et al. investigated all aspects of the root to determine the locations of apical foramina and reported that apical foramina were frequently located at the apical aspect of the root.[19] The result of this study was in accordance with the findings of Martos et al., and the frequencies of the locations of the minor apical foramina on the root surface are presented in Table 1 and Table 2.[19]

CONCLUSION

The results of this study supported the previous studies that noted the high complexity of the apical region. Therefore, clinicians should keep this point in mind during endodontic and surgical interventions and use proper equipment, such as electronic apex locater, x-ray, tomography and MRI to improve treatment quality. Clinicians should consider that many minor apical foramina widths may be larger than an ISO-15-sized file; therefore, the final preparation size must be determined accordingly.

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Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Evren Sarıyılmaz, Ali Çağın Yücel;* ***Design:****Evren Sarıyılmaz, Ali Çağın Yücel;* ***Control/Supervision:*** *Ali Çağın Yücel;* ***Data Collection and/or Processing:****Evren Sarıyılmaz;* ***Analysis and/or Interpretation:*** *Evren Sarıyılmaz, Ali Çağın Yücel;* ***Literature Review:*** *Evren Sarıyılmaz;* ***Writing the Article:*** *Evren Sarıyılmaz, Ali Çağın Yücel;* ***Critical Review:*** *Ali Çağın Yücel;* ***References and Fundings:*** *Evren Sarıyılmaz, Ali Çağın Yücel;* ***Materials:*** *Evren Sarıyılmaz.*

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