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ORIGINAL ARTICLE

Morphology of apical foramen in permanent molars and premolars in a Turkish population

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Abstract

Objective: To determine the number, shape and diameter of minor apical foramina, the distance between apical foramina and anatomical apex and the frequency of accessory foramina in a Turkish population. ***Materials and methods:*** Eight hundred permanent maxillary and mandibular teeth were collected. The roots were stained with methylene blue and the apices were examined with a stereomicroscope (×40) and transferred to a computer to perform the measurements using Adobe Photoshop software. ***Results:*** The incidence of one apical foramen was highest in distobuccal roots of the maxillary first molars and was lowest in the maxillary first premolars with single roots. The distance of deviation in all the teeth was between 0.271–0.519 mm. The frequency of accessory foramina was between 30–70% for the various tooth types. ***Conclusions:*** The results of this *in vitro* study indicate that the morphology of apical foramina in this Turkish population may present highly complex anatomical variations.

Key Words: *anatomical root apex, apical foramen, stereomicroscopy*

Introduction

The goals of root canal treatment are the elimination of micro-organisms and debris in root canal systems and the preparation of the root canal system for obturation [1]. The narrowest portion of the canal is referred to as the apical constriction. Ideally, the apical terminus of preparation should be at this point and this should result in a small wound and optimal healing conditions [2]. To determine the terminus or stopping point for clinical procedures, radiographs may be used. However, this procedure may be misleading as to working length, especially if the foramen deviates in the buccal or lingual plane of the root [3] and because apical constriction is not always positioned at the radiological apex. Thus, misinterpretation of radiographs may cause an incorrect determination of working length. As a consequence, over-instrumentation and over-filling is inevitable [4].

In terms of over-instrumentation, defining the apical diameter is as important as defining the deviation of apical foramina from the apex. During preparation, the apical size should be kept as small as possible [5]. If root canal instruments or filling materials go beyond the apical foramen, periapical tissues could become infected and there may be a lack of healing following the root canal procedures [6]. Determination of the apical foramen diameter is therefore highly important to avoid over-instrumentation. Knowledge of the morphology of the apical third would also be helpful in the preparation and disinfection procedure for root canal treatment. Furthermore, knowledge of the diameter of physiological foramina could be used to determine the master apical file (MAF) [7,8]. However, most teeth do not have an apical constriction [9]. This finding may be due to age, although pathological cases such as root resorption exist [10].

Despite the fact that there are some studies of the morphology of root canals in Turkish populations [11,12], no study has yet been carried out regarding the morphology of the apical foramina in this population. Thus, the purpose of this study is to determine the number, shape and diameter of minor apical foramina, the distance between the apical foramina and the anatomical apex and the frequency of accessory foramina in this Turkish population.

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Materials and methods

A total of 800 permanent maxillary and mandibular teeth (premolars and molars) from a Turkish population were included in this study. The teeth were stored in 5.25% sodium hypochlorite. The teeth had intact crowns and were identified as maxillary or mandibular first and then as second premolars or first and second molars. Roots with fractures, resorption or that had received any previous root canal treatment were discarded. The teeth were cleaned of any soft tissues or calculus in and around the foramen area with a size 8 K file (Mani Inc., Tochigi-Ken, Japan). The roots were placed in methylene blue and they were then washed under running water for 10 min and dried with pressurized air before the study.

The apical region of the root was examined at 40× magnification with a stereomicroscope (Novex, Arnhem, Holland). If there was more than one foramina, each foramen was placed parallel to the objective lens. Photographs were taken of the focus area on the root. These photographs were transferred to a computer to perform the measurements. Measurements were performed using software (Photoshop, Adobe Systems, San Jose, CA). This procedure is shown in Figures 1 and 2.

Each root was oriented until the physiological foramen was located parallel to the objective lens and the photographs were taken with the foramen in the middle of the objective lens. By adjusting the focus, the minor apical foramen was confirmed. The minor apical foramen was defined as having the smallest diameter in the region of the apical foramen. As the canal widens from the minor apical foramen to the major apical foramen, the major apical foramen was considered to be the region of the apical foramen with the outermost diameter. Thus, the apical foramen was defined as the opening of the root canal on the external root surface. If the foramen's diameter was narrower than 0.1 mm, it was recognized as an accessory foramen (Figure 3). The size, shape and deviation of the minor apical foramina, as well as frequency accessory foramina were recorded. The minimum and maximum diameters of each minor apical foramen were measured. Differences between maximum and minimum diameters of the minor apical foramina greater than 0.02 mm were considered to be indicative of an oval shape. Minor apical foramina were defined as a round, oval or irregular in form. To determine the distance between the minor apical foramen and the anatomical apex, a straight line was traced to the root from the most apical point of the foramen to a tangent line at the most apical point of the anatomical apex (Figure 4).

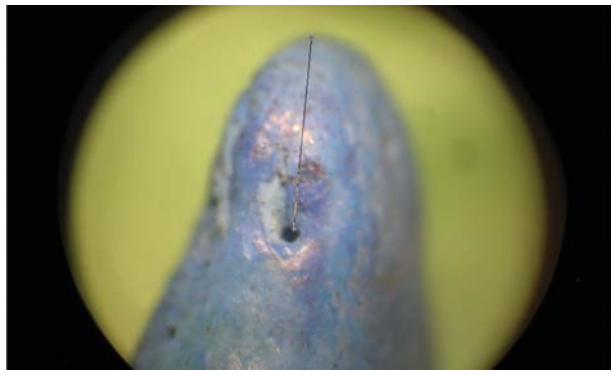

Figure 2. Measurament of the distance between apical foramina and anatomic apex. The marked area with red box shows the measurement of the distance as mm.

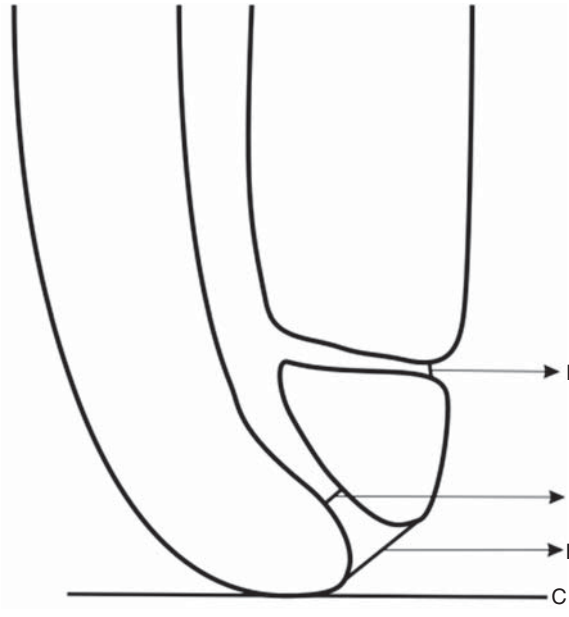

Figure 1. Morphology of apical foramen. (A) Minor apical foramen, (B) Major apical foramen, (C) Anatomical apex, (D) Accessory foramen.

Results

Apical foramina

In all, 1982 foramina were viewed and assessed for the whole study. The distance between the minor apical foramina and the anatomical apex, the frequency of accessory foramina and the number of apical

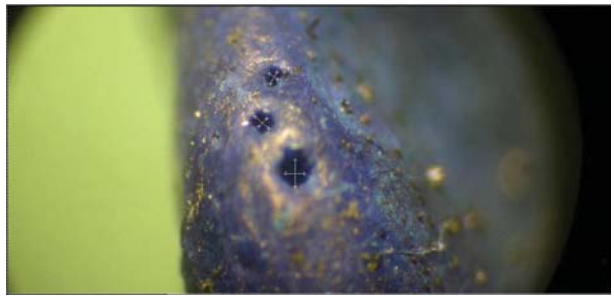

Figure 3. One minor apical foramen and two accessory foramina at apex, measurement of maximum and minimum diameters of each foramen.

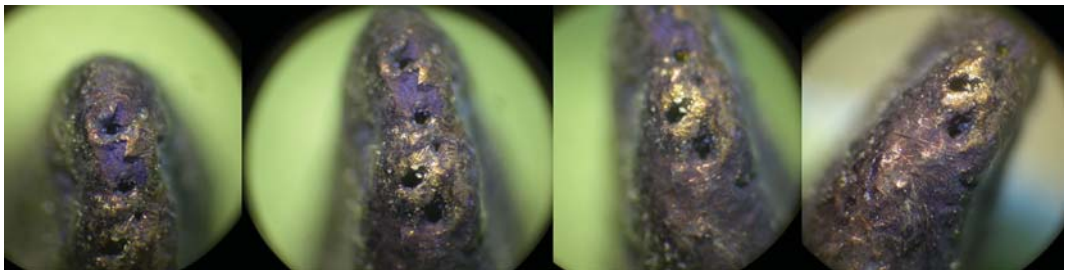

Figure 4. Each foramen focused parallel to objective lens one-by-one then measurements were performed on these different photographs.

foramina, as well as the shape of apical foramina and the maximum and minimum diameters of apical foramina of the first and second molars and premolars, are shown in Tables I,II,III,IV.

Number of apical foramina

The number of apical foramina by tooth type is shown in Table I. The incidence of one apical foramen was highest in the distobuccal roots of maxillary first molars and was least in the maxillary first premolars with single roots. The greatest variation of a single apical foramen was observed in the mesial roots of maxillary first and second molars. In one of the mandibular second molars' distal roots, five apical foramina were observed.

Shape of apical foramina

The most common shape of the minor apical foramen was oval (48.36%). The highest ratio of the irregular form of apical foramina was found in mandibular first premolars (49.25%) and the oval form of apical foramina was found most often in maxillary first premolars with single roots (67.24%). The round form of apical foramina was found most often in

Table I. Number of apical foramina and frequency of accessory foramina by tooth type.

	Number of apical foramina by tooth type					Frequency of accessory foramina by tooth type					
	1	2	3	4	5	0	1	2	3	4	5
Mandibular teeth											
First premolar	69	28	3	0	0	76	13	8	1	1	1
Second premolar	75	22	3	0	0	71	23	3	3	0	0
First molar											
mesial root	77	20	2	0	0	74	24	0	2	0	0
distal root	77	15	3	1	0	73	23	2	2	0	0
Second molar											
mesial root	65	27	8	0	0	65	24	7	4	0	0
distal root	63	14	3	0	1	57	39	2	2	0	0
Maxillary teeth											
First premolar											
buccal root	37	17	5	0	0	54	8	5	1	1	0
palatinal root	49	16	4	0	0	43	11	13	2	0	0
single root	10	17	2	2	0	19	8	4	0	0	0
Second premolar	55	35	10	0	0	73	10	9	6	2	0
First molar											
mesiobuccal root	37	44	15	4	0	71	17	5	5	0	0
distobuccal root	80	15	5	0	0	69	26	4	0	1	0
palatal root	77	19	4	0	0	78	17	3	0	2	0
Second premolar											
mesiobuccal root	48	32	19	1	0	60	20	6	11	3	0
distobuccal root	61	35	4	0	0	58	20	12	10	0	0
palatal root	69	28	3	0	0	70	22	2	6	0	0

Table II. Minimum and maximum diameter and shape of apical foramina.

	Minimum diameter of apical foramina (mm), Mean ± SD	Maximum diameter of minor apical foramina (mm), Mean ± SD	Shape of apical foramina (%)		
			Irreg.	Oval	Round
Mandibular teeth					
First premolar	0.173 ± 0.076	0.27 ± 0.128	49.25	35.82	14.93
Second premolar	0.141 ± 0.058	0.217 ± 0.078	34.37	52.34	13.29
First molar					
mesial root	0.101 ± 0.059	0.218 ± 0.083	33.58	45.31	21.11
distal root	0.143 ± 0.061	0.212 ± 0.091	32.33	41.35	26.32
Second molar					
mesial root	0.148 ± 0.061	0.25 ± 0.129	34.26	54.54	11.2
distal root	0.148 ± 0.058	0.222 ± 0.087	28.86	48.32	22.82
Maxillary teeth					
First premolar					
buccal root	0.175 ± 0.089	0.221 ± 0.108	31.4	48.83	19.77
palatinal root	0.199 ± 0.093	0.288 ± 0.120	21.5	47.31	31.19
single root	0.161 ± 0.083	0.302 ± 0.148	29.31	67.24	3.45
Second premolar	0.168 ± 0.092	0.259 ± 0.126	38.06	41.29	20.65
First molar					
mesiobuccal root	0.153 ± 0.075	0.210 ± 0.092	16.67	45.7	37.63
distobuccal root	0.156 ± 0.061	0.213 ± 0.074	16	49.6	34.4
palatal root	0.185 ± 0.101	0.261 ± 0.138	18.91	48.81	32.28
Second premolar					
mesiobuccal root	0.139 ± 0.05	0.204 ± 0.086	20.81	58.38	20.81
distobuccal root	0.144 ± 0.048	0.139 ± 0.057	20.98	41.26	37.76
palatal root	0.157 ± 0.053	0.225 ± 0.130	17.91	47.76	34.33

distobuccal roots of maxillary second molars (37.76%). The lowest ratio of the irregular form of apical foramina was found in distobuccal roots of maxillary first molars (16%), with the oval form of apical foramina found least often in mandibular first premolars (32.82%) and the round form of apical foramina found least often in maxillary first premolars with single roots (3.45%).

Diameters of apical foramina

The mean maximum diameter of minor apical foramina ranged from 0.139 mm (distobuccal roots of maxillary second molars) to 0.302 mm (maxillary first premolars with single roots). The mean minimum diameter of minor apical foramina ranged from 0.101 mm (mesial roots of mandibular first molars) to 0.199 mm (palatinal roots of maxillary first premolars). The differences between the wide and narrow diameters of the apical foramina by tooth type are shown in Table II. In 88% of the teeth, the difference was less than or equal to 0.15 mm. In 12% of the teeth, the difference was longer than 0.15 mm.

Deviation of the minor apical foramina from the anatomical apex

The highest mean value of the distance between the minor apical foramina and the anatomical apex was observed in mesiobuccal roots of maxillary first molars (0.519 mm). The lowest mean value was observed in palatal roots of maxillary second molars (0.271 mm) (Table III).

Frequency of accessory foramina

The highest frequency of accessory foramina was found in mesiobuccal roots of maxillary second molars (77%). The lowest frequency of accessory foramina was found in mesial roots of mandibular first molars (30%).

Discussion

Rates showing the presence of two anatomical foramina in the mesial (23.5%) and distal (2.5%) roots of mandibular molars were lower than those reported by

Table III. The distance between minor apical foramina and anatomical apex.

	Minimum	Maximum	Mean	SD
Mandibular teeth				
First premolar	0	1.94	0.305	0.358
Second premolar	0	1.68	0.390	0.448
First molar				
mesial root	0	1.1	0.307	0.318
distal root	0	1.17	0.325	0.343
Second molar				
mesial root	0	1.58	0.454	0.356
distal root	0	2	0.425	0.348
Maxillary teeth				
First premolar				
buccal root	0	1.79	0.258	0.306
palatinal root	0	1.74	0.374	0.461
single root	0	1.31	0.291	0.265
Second premolar	0	1.74	0.348	0.343
First molar				
mesiobuccal root	0	1.83	0.519	0.482
distobuccal root	0	1.83	0.454	0.478
palatal root	0	1.53	0.423	0.392
Second premolar				
mesiobuccal root	0	1.65	0.328	0.412
distobuccal root	0	1.51	0.355	0.398
palatal root	0	1	0.271	0.318

other authors [13,14]. In the present study, the incidence of two apical foramina was 44% and 32% for the maxillary first and second molar mesiobuccal roots, respectively. Previous reports have placed frequency rates for mesiobuccal foramina in the range of 17–80% [15,16]. Additionally, unlike most of the previous studies [13,14], the mesiobuccal roots of maxillary molars had a higher frequency of three foramina (15%). This may indicate that there is a high likelihood of three separate canals in the mesiobuccal root in the Turkish population. However, the presence of three anatomical apices may indicate either the presence of one or two root canals dividing into three or an apical delta. This finding reinforces the argument that a failure to find and treat existing canals in molars will worsen the long-term prognosis [17]. Consequently, when considering root canal procedures in permanent molars, more emphasis should be placed on the importance of using magnification to locate additional canals [16,18].

In the present study, the shape of apical foramina was considered to be round when the difference between the wide and the narrow diameters of an apical foramen was equal to or less than 0.02 mm. This study did not find a typical pattern for the apical foramina. However, the oval form was the most prevalent shape for all types of teeth except the mandibular first premolar, in which an irregular shape was the most prevalent. This result is clinically important because many oval-shaped root canals are difficult to shape completely without perforating or significantly weakening the root [14]. The frequencies of the oval canals were lower than those identified by Arora and Tewari [13] and Gani and Visvisian [19]. Other forms of apical foramina, such as triangular, kidney-bean shaped or irregular forms, were observed in 27.5% of the roots. While the dimension of the apical foramen has been a point of controversy, the measurement of the apical foramen's diameter should provide clues to the size of the master apical file during root canal preparation [7,8]. In this study, the mean maximum diameter of the minor apical foramina ranged from 0.14–0.3 mm and the mean minimum diameter ranged from 0.10–0.20 mm. These findings are lower than the findings of Morfis et al.'s [20] study and agree to a great extent with those reported in other investigations [13,14]. Clinically speaking, based on the results of the narrow diameter of the physiological foramen in the Turkish population, the initial apical file size could be tentatively determined before root canal enlargement. However, when selecting an initial file according to the results, the high standard deviations obtained in this investigation indicate possible failure.

Since most canals are oval in their cross-sectional shape, the goal of the shaping procedures should be to make the final apical instrument size correspond to the largest diameter of the oval in order to make the canals round. In other words, the final instrument size must be large enough to touch all the canal walls [13]. The difference between the wide and narrow diameters of the apical foramen region for all tooth groups in this population was less than or equal to 0.15 mm in 88% teeth. Therefore, the enlargement up to three instrument sizes larger than the first binding file in the apical constriction region will shape the minor apical foramen to a round form in 88% of teeth, which is a remarkable rate. In only 12% of teeth was the difference greater than 0.15 mm, so enlarging the size to four or more than four from the first binding file in the apical constriction region will shape the minor apical foramen to a round form in this percentage of teeth.

For this study, data was collected on the distance from a tangent line at the most apical point of the anatomical apex to the most apical point of the minor foramen [2]. The mean distances ranged from 0.27–0.52 mm. Previous studies, which used different methods, have described mean distances between the apical foramen and the most apical end of the root ranging from 0.2–3.80 mm [20–24]. Variations among findings may be explained by the differences among the examination methods, the number of teeth

Table IV. The percentage of difference between maximum and minimum diameters of apical foramina by tooth type.

	d ≤ 0.15 (mm)	0.15 < d ≤ 0.20	0.20 < d ≤ 0.25	0.25 < d ≤ 0.30	0.30 < d ≤ 0.35	d > 0.35
Mandibular first premolar	82	8	3	2	3	2
Mandibular second premolar	91.6	4.67	1.87	0.93	—	0.93
Mandibular first molar						
mesial	94.84	1.94	1.29	1.29	—	0.64
distal	96.77	3.23	—	—	—	—
Mandibular second molar						
mesial	84.93	6.85	2.74	1.37	1.37	2.74
distal	88.57	8.57	1.43	—	—	1.43
Maxilllary first premolar						
buccal	82.7	7.69	5.77	1.92	1.92	—
palatinal	80.44	10.88	2.17	2.17	2.17	2.17
single root	67.85	10.71	3.58	7.14	3.58	7.14
Maxillary second premolar	81.4	9.8	4.8	0.8	1.6	1.6
Maxillary first molar						
mesiobuccal	91.7	5.52	1.39	—	—	1.39
distobuccal	90.8	3.07	1.53	3.07	1.53	—
palatinal	89.62	1.89	2.83	0.94	1.89	2.83
Maxillary second molar						
mesiobuccal	90.47	1.19	4.77	—	1.19	2.38
distobuccal	92.30	4.48	1.1	—	1.1	1.1
palatinal	98.49	1.51	—	—	—	—
Total	87.78	1.51	2.39	1.35	1.21	1.65

d, distance between wide and narrow diameter of apical foramina.

evaluated and the racial differences of patients, as well as the age of the patients from whom the teeth were extracted [14,21,25]. The uncertain nature of the position of the apical constriction with respect to the radiographic apex further strengthens the need to use apex locators rather than radiographs to determine canal length [13].

As reported in previous studies [13,14], a foramen was described as an accessory foramen when it was narrower than 0.10 mm. The highest frequency of accessory foramina observed was in the mesiobuccal roots of maxillary second molars, which was a finding that was similar to previous reports [23]. The lowest frequency of accessory foramina was found in mesial roots of mandibular first molars. In addition, maxillary first premolars with single roots had a high prevalence of accessory foramina, which is similar to the prevalence reported in previous studies [13,14]. These accessory foramina suggest either the extensive ramifications of the root canal or the presence of the multiple canals at the apex. Clinically, these findings may be important because the complete debridement of these anatomical areas is impossible through chemomechanical preparation and necrotic pulp tissues and micro-organisms may remain in the apical portion, contributing to post-treatment periodontitis [13,20,26]. This anatomical scenario also suggests that it is impossible to reliably eradicate all pulp tissue and/or micro-organisms from infected root canals with chemomechanical preparation alone and it further suggests that medicating the infected root canals with an antimicrobial agent or scope of surgical endodontics for the management of such teeth is necessary [27,28]. Furthermore, the use of radiography for morphological studies is not reliable because the radiography does not give information concerning the buccal and lingual aspect of the root [14]. Other investigative methods, such as scanning electron microscopy [20], three-dimensional imaging [29] and high-resolution tomography [30], have been used to reduce uncontrollable variables in research and to increase measurement accuracy. In the present study, the examination of the apical region was performed using stereomicroscope at a ×40 magnification.

Conclusions

The data obtained in examining teeth from a Turkish population indicated that the morphology of the apical foramina is highly complex, exhibiting significant anatomical variations. These anatomical variations

should be considered during surgical and non-surgical endodontic intervention.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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