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The morphology of the apical foramen in posterior teeth in a North Indian population

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Abstract

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Aim To determine the position and shape of the apical foramina in posterior teeth derived from an Indian population.

Methodology A total of 800 freshly extracted maxillary and mandibular premolar and molar teeth from a native Haryana population were collected. Apices of teeth were stained with methylene blue and then examined stereomicroscopically ($40\times$). The following observations were made: number of apical foramina; size and shape of the minor apical foramen; accessory foramina frequency, and deviation of the minor apical foramina (frequency and distance) from the apex.

Results The mean maximum and minimum diameter of the minor apical foramina ranged from 0.158 to 0.323 mm. The most common minor apical foramen shape was oval (81%). Frequency of accessory foramina was between 2% and 41% for the various tooth types. The frequency of deviation of the minor apical foramina from the anatomic apex varied from 43% to 83% and the distance of deviation in all the teeth was between 0.052 and 2.921 mm.

Conclusions The incidence of oval canals was higher in this Indian population compared to other populations. In 92% and 96% of teeth the difference between the maximum and the minimum diameter of all foramina was less than or equal to 0.20 and 0.25 mm, respectively. Therefore, four to five instrument sizes larger than the first binding file would have been necessary to shape the minor apical foramen of more than 95% of the teeth included in this study to make them round.

Keywords: anatomical apex, computer-aided stereomicroscope, major apical foramina, minor apical foramina.

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Introduction

The main objective of root canal treatment is thorough mechanical and chemical cleansing of the pulp cavity and its complete filling with an inert material (Kuttler 1958). From the early work of Hess & Zurcher (1925) to the most recent studies demonstrating anatomic complexities of the root canal system, it has been established that a root with a tapering canal and a single foramen is the exception rather than the rule. Root canal morphology especially in the apical third is a critically important factor during conventional root canal treatment and surgical endodontics.

The apical constriction, when present, is the narrowest part of the root canal, and preparation to this point should result in a small wound and optimal healing conditions (Ricucci & Langeland 1998). The dimension of the apical constriction has been a focus of debate. The horizontal dimension of the root canal system is not only more complicated than the vertical dimension (root canal length or working length) but also more difficult to investigate. These measurements could provide clues for the size of master apical file

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during root canal preparation (Ricucci 1998, Jou *et al.* 2004) and can have an impact on the selection of the best instrumentation technique (Cheung *et al.* 2007).

The clinical philosophy that apical sizes should be kept as small as possible (Buchanan 2000), rather than as large as required, disregards the existing scientific facts. Studies have reported better debridement and reduced bacterial load with larger apical preparation (Ram 1977, Chow 1983, Dalton *et al.* 1998, Siqueira *et al.* 1999, Shuping *et al.* 2000). Dental manufacturers and some individuals are suggesting apical instrumentation with rotary instruments of sizes 20, 25 and 30 (Spangberg 2001). However this gives the erroneous impression that apical diameters of canals are small in size; even though the dimensions of the apical foramina and the apical canal region are reported to be larger (Morfis *et al.* 1994, Gani & Visvisian 1999, Wu *et al.* 2000, Marroquin *et al.* 2004).

Wide variations in the dimensions of the apical constriction have been reported. Cheung *et al.* (2007) reported the mean value for the longest and the shortest diameter of the apical constriction of mesial and distal canals of C-shaped mandibular second molars to be 0.26 : 0.15 mm and 0.36 : 0.22 mm, respectively. Marroquin *et al.* (2004) reported mean narrow (0.20 mm) and wide (0.26 mm) diameters of minor apical foramina in mandibular molars, 0.18–0.25 mm in the mesio-buccal and distobuccal roots and 0.22–0.29 mm in the palatal root of the maxillary molars. Morfis *et al.* (1994) reported a mean diameter of 0.26 and 0.39 mm for the mesial and distal canals, respectively, in mandibular molars (without defining the exact site of measurement).

Previous studies have frequently demonstrated that the apical foramen is not always located at the tip of the root. The frequency of deviation of the major foramen from the anatomical apex ranged from 46% to 92% and the mean distance between them ranged from 0.2 to 1.38 mm (Kuttler 1955, Green 1956, 1960, Palmer et al. 1971, Burch & Hulen 1972, Pineda & Kuttler 1972, Blasković-Subat et al. 1992, Morfis et al. 1994, Marroquin et al. 2004, Cheung et al. 2007). Furthermore, these studies have shown that frequency of deviation varies in different races. If the foramen deviates in the buccal/lingual plane, it is difficult to locate its position using radiographs alone (Schaeffer et al. 2005). ElAyouti et al. (2001, 2002) also reported that a seemingly accurate working length ending radiographically 0-2 mm short of the radiographic apex can result in overestimation of working length in 51% of the root canals. Therefore, misinterpretation of dental radiographs may lead to an incorrect determination of working length and to subsequent complications of over-instrumentation and overfilling of the root canal (Seltzer *et al.* 1971).

The cosmopolitan nature of urban populations means that endodontists treat an increasing number of patients of different and mixed racial origin. It is, therefore, important to be aware of the frequency of racially determined anatomic variations. A number of studies have shown different trends in morphology of roots and canals amongst the different races (Caliskan *et al.* 1995, Gulabivala *et al.* 2001, 2002, Ng *et al.* 2001, Wasti *et al.* 2001, Sert & Bayirli 2004, Al-Qudah & Awawdeh 2006). Additionally, no such morphometric study has yet been conducted in Indian populations.

In view of conflicting findings regarding the apical zone and scarce reports on teeth of Indian origin, the objective of this study was to determine further the number, shape, diameter of the apical foramina as well as the incidence of their deviation from the anatomical apex, the distance between them and the frequency of accessory foramina in an Indian population.

Materials and methods

A total of 800 freshly extracted human permanent maxillary and mandibular *posterior* teeth, with completely formed apices, obtained from a North Indian (Haryana) population were included. Teeth were collected from a general district hospital attended by local population. Ethnicity of the population was further verified from the outpatient records. Teeth were extracted because of periodontal or pulpal disease. Following extraction teeth were washed under tap water, and stored in 5% sodium hypochlorite (Aroma Agencies, Mumbai, Maharashtra, India) and used within 6 months of extraction. The teeth were identified as maxillary or mandibular first and second premolars, or first and second molars.

One hundred teeth, with intact crowns (for clear identification), in each group were selected according to strict inclusion and exclusion criteria as described by Marroquin *et al.* (2004). Primary teeth and roots with fractures, resorption, or underdevelopment ($40 \times$ magnification) or that had received any previous endodontic treatment were discarded (Marroquin *et al.* 2004). Soft tissues around and in the foramen area were removed with a size 6 K file (Dentsply Maillefer, Ballaigues, Switzerland) at $40 \times$ magnification. The roots were then placed in methylene blue (Macsen Laboratories, Udaipur, Rajasthan, India), washed under

running water for 10 min, and dried with pressurized air before examination.

A computer-aided stereomicroscope with 40×magnification (Stereo zoom microscope RSM-9; Radical Scientific Equipments Pvt. Ltd., Ambala Cantt, Haryana, India) and VideoTesT-Size 5.0 measurement software (VideoTesT, St Petersburg, Russia) was used. Measurement accuracy was assured through calibration between a micro scale with 0.1 mm markings and the software. The measuring dialogue menu was set in millimetres and adjusted to three decimal places.

On the external root surface, the opening of the root canal was called the apical foramen (AF) and its outermost diameter was termed the 'major apical foramen' (Fig. 1). The minor apical foramen (apical constriction) was considered to be the region of the apical foramen with the smallest diameter. From the minor apical foramen the canal widens as it approaches the major apical foramen (Fig. 1). In clinical practice, the minor apical foramen is a more consistent anatomical feature (Ponce & Vilar Fernandez 2003) and is the preferred landmark for the apical end-point for root canal treatment. The 'anatomic apex' was defined as the most apical root structure (Fig. 1), and was traced by marking with red ink. These three anatomical entities could, theoretically, coincide in one. A foramen was categorized as accessory when its diameter was narrower than 0.10 mm (Marroquin et al. 2004).

After initial confirmation of tooth type, the root morphology of the apical area was examined under 40×magnification. Teeth were oriented until the major apical foramen was located in the middle of and parallel to the objective lens. The image of the minor apical foramen was then captured by regulating the focus.



Figure 1 Diagrammatic representations of the morphological features investigated.

Here, minor foramen was that part of the apical foramen with the smallest planar dimension, as observed by focusing below the major apical foramen (Cheung *et al.* 2007). If a root had more than one apical foramen, then each foramen was focused separately parallel to objective lens by changing the orientation of tooth and individual photographs were captured.

The following observations were then made:

- 1. size of minor apical foramen,
- 2. shape of minor apical foramen,
- 3. accessory foramina frequency (if found), and

4. deviation of the minor apical foramen (in mm) from the apex.

Diameters of the minor apical foramen

The widest and narrowest diameters of each minor apical foramen were measured using the length measuring mode of the software and defined as the maximum and the minimum diameters, respectively (Fig. 2).

Shape of the minor apical foramen

A minor apical foramen with a difference greater than or equal to 0.02 mm between its maximum and minimum diameters was considered to have an oval shape. This criterion was established according to Marroquin *et al.* (2004) in consideration of the ISO tolerances for root canal instruments. The shape of the minor apical foramen was accordingly determined to



Figure 2 Two minor apical foramina and one accessory foramen (top most) at apex, measurement of maximum and minimum diameters of each foramen has been made.



Figure 3 Method for measuring distances between the minor apical foramen and the anatomic apex. Each foramen was separately focused parallel to the objective lens and measurements were made on different photographs. AA denotes anatomic apex, traced by marking with red ink.

have either a round, oval, or irregular (triangular, kidney, or irregular) form.

Frequency and distance of deviation of minor apical foramen from anatomical apex

If the minor apical foramen was not located at the anatomical root apex, but at a more cervical position on the long axis of the root, a straight line parallel to the root from the most apical point of the foramen to a tangent line at the most apical point of the anatomical apex was used to determine the distance between the minor apical foramen and anatomical apex (Marroquin *et al.* 2004) (Fig. 3).

The statistical data were arranged by means, maximum, minimum and SD.

Results

A total of 2004 foramina were investigated. The distance between the minor apical foramen and anatomical apex; frequency of accessory foramina; number, shape and diameter of apical foramina in each root of maxillary and mandibular premolars and first and second premolars are shown in Tables 1–5. In tables S1–S14 (supporting information) the mean values for minimum and maximum diameters and distance of

deviation are reported separately for each root with one, two, three, four, and five foramina. In tables S15– S16 minimum and maximum diameters of accessory foramina have been reported.

Number of apical foramina

Mandibular teeth

The number of apical foramina in all *posterior* teeth is described in Table 1. In the mandibular *posterior* teeth the incidence of a single apical foramen ranged from 64% to 81% except in the mesial root of mandibular first molars (33%). As many as five apical foramina were observed in 1% teeth in mandibular first and second premolars and mesial roots of first molars. The greatest variation from a single apical foramina was observed in the mesial roots of mandibular first molars with an incidence of two, three, four, five foramina in 46%, 16%, 4% and 1%, respectively.

Maxillary teeth

In maxillary teeth the greatest variations from a single apical foramina were observed in both first and second premolars followed by the mesiobuccal root of first molars. The incidence of two foramina was 57%, 38% and 37% and more than two foramina in 17%, 21% and 9% of teeth, respectively. In maxillary teeth five apical

Tabl	le	1	Num	ber	of	' apical	f	oramina	by	tooth	type
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	Single	Two	Three	Four	Five
Mandibular teeth					
Mandibular first premolar	70	24	3	2	1
Mandibular second premolar	74	16	6	3	1
Mandibular first molar					
Mesial root	33	46	16	4	1
Distal root	75	22	2	1	Х
Mandibular second molar					
Mesial root	64	33	3	Х	Х
Distal root	81	18	Х	1	Х
Maxillary teeth					
Maxillary first premolar	25	57	13	4	Х
Maxillary second premolar	41	38	16	2	3
Maxillary first molar					
Mesiobuccal root	54	37	6	3	Х
Distobuccal root	91	8	Х	Х	Х
Palatal root	78	20	2	Х	Х
Maxillary second molar					
Mesiobuccal root	61	31	5	3	Х
Distobuccal root	80	13	Х	Х	Х
Palatal root	88	11	1	Х	Х

Table 2	Frequency	of accessory 1	foramina by	tooth type
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	0	1	2	3	4	5	Total
Mandibular teeth							
Mandibular first premolar	91	7	2	Х	Х	Х	11
Mandibular second premolar	91	6	0	1	2	Х	17
Mandibular first molar							
Mesial root	86	13	1	Х	Х	Х	15
Distal root	96	4	Х	Х	Х	Х	4
Mandibular second molar							
Mesial root	95	5	Х	Х	Х	Х	5
Distal root	94	6	Х	Х	Х	Х	6
Maxillary teeth							
Maxillary first premolar	87	8	1	3	Х	1	24
Maxillary second premolar	72	12	3	3	1	2	41
Maxillary first molar							
Mesiobuccal root	92	5	2	1	Х	Х	12
Distobuccal root	95	5	Х	Х	Х	Х	5
Palatal root	93	5	2	Х	Х	Х	9
Maxillary second molar							
Mesiobuccal root	86	7	5	Х	2	Х	25
Distobuccal root	96	4	Х	Х	Х	Х	4
Palatal root	98	2	Х	Х	Х	Х	2

foramina were found in maxillary second premolars only, with an incidence of 3% (Fig. 4). Distobuccal roots of first and second molars showed simpler anatomy having a maximum two apical foramina only, and no main apical foramina in 1% teeth.

Frequency of accessory foramen

There was a higher frequency of accessory foramina in maxillary premolars followed by mandibular premolars (Table 2). The highest frequency of accessory foramina was in maxillary second premolars (41%). Values as low as 2%, for palatal roots of maxillary second molars were also obtained.

Deviation of minor apical foramina from the anatomical apex

Deviation of the minor apical foramina from the anatomical apex was seen in all teeth but there was no conclusive pattern of variation (Table 3). Frequency of deviation of minor apical foramina (Table 3) from the apex varied from 43% in maxillary first premolars to 83% in mandibular first premolars.

The highest mean value of the distance between the minor apical foramen and the anatomical apex was observed in the mesiobuccal root of maxillary first molars (0.996 mm). The lowest value of 0.632 mm was observed for the distobuccal root of maxillary second molars (Table 3).

Diameters of minor apical foramina

The mean maximum diameter (Table 4) of the minor apical foramina ranged from 0.230 mm (distobuccal root of maxillary second molars) to 0.323 mm (distal root of mandibular second molars). The mean minimum diameter (Table 5) of the minor apical foramina ranged from 0.158 mm (mandibular second premolars) to 0.227 mm (distal root of mandibular second molars).

Discussion

A digital stereomicroscope with integrated software was used to provide accurate measurement of a large number of teeth. Teeth were oriented until the apical foramen was located in the middle of and parallel to the objective lens to allow measurement of the true dimensions of the minor apical foramen irrespective of the curvature that a canal follows inside the root.

If the apical foramen was located at a more cervical position on the long axis of the root, a straight line parallel to the root from the most apical point of the foramen to a tangent line at the most apical point of the anatomical apex was drawn for each foramina. This determined the true distance not the vertical distance between the apical foramen and anatomical apex. However this distance can not be measured *in vivo* because of limitations of radiographs in identifying accurately the foramina on buccal/lingual root surfaces

Table 3 Distance (in mm) and %age
deviation of minor apical foramina from
the apex by tooth type

	Minimum	Maximum	Average	SD	%Deviation
Mandibular teeth					
First premolar	0.112	2.186	0.796	0.415	83
Second premolar	0.052	2.892	0.781	0.463	78
First molar: mesial root	0.154	2.808	0.834	0.496	50
First molar: distal root	0.167	1.617	0.817	0.297	68
Second molar: mesial root	0.127	2.202	0.78	0.465	46
Second molar: distal root	0.065	2.031	0.809	0.322	44
Maxillary teeth					
First premolar	0.18	2.03	0.78	0.391	43
Second premolar	0.122	2.523	0.984	0.407	49
First molar: mesiobuccal root	0.176	2.921	0.996	0.676	59
First molar: distobuccal root	0.225	2.224	0.824	0.441	54
First molar: palatal root	0.26	2.455	0.924	0.466	68
Second molar: mesiobuccal root	0.276	2.527	0.992	0.580	59
Second molar: distobuccal root	0.106	1.433	0.632	0.319	49
Second molar: palatal root	0.122	0.873	0.719	0.313	61

Table 4 Maximum diameter (in mm) ofminor apical foramina by tooth type

	Minimum	Maximum	Average	SD
Mandibular teeth				
First premolar	0.1	1.169	0.256	0.122
Second premolar	0.104	1.45	0.241	0.144
First molar: mesial root	0.102	1.265	0.261	0.153
First molar: distal root	0.116	0.585	0.300	0.104
Second molar: mesial root	0.112	0.793	0.303	0.143
Second molar: distal root	0.122	1.168	0.323	0.142
Maxillary teeth				
First premolar	0.106	0.553	0.24	0.092
Second premolar	0.103	1.394	0.254	0.139
First molar: mesiobuccal root	0.1	0.835	0.263	0.125
First molar: distobuccal root	0.103	0.524	0.257	0.082
First molar: palatal root	0.108	0.794	0.320	0.146
Second molar: mesiobuccal root	0.105	0.509	0.244	0.098
Second molar: distobuccal root	0.103	0.43	0.230	0.078
Second molar: palatal root	0.117	0.794	0.309	0.12

(Schaeffer *et al.* 2005), as well as the inability of the electronic apex locators in locating the canal terminus with 100% accuracy (Wrbas *et al.* 2007, ElAyouti *et al.* 2009).

The frequency of deviation of the minor apical foramen from the apex (43-83%), distances of the minor apical foramina from the apex (0.052-2.921 mm) and mean distance of minor apical foramina from anatomic apex reported in the present study (0.632-0.996 mm) compare with the literature (Kuttler 1955, Green 1956, 1960, Palmer *et al.* 1971, Pineda & Kuttler 1972, Vertucci 1984, Blasković-Subat *et al.* 1992, Morfis *et al.* 1994, Marroquin *et al.* 2004). The minor differences observed between various studies may be explained by the different measuring methods, by the different apical foramen definitions used and by difference in reference points to measure the distances. These results demonstrate the

complexity of the apical zone in this Indian population and the similarity with other parts of the world. Thus, they suggest that the endodontic principles and practices being followed in the other parts of the world can also be applied to this Indian population. The unpredictable nature of the position of the apical constriction with respect to the radiographic apex further strengthens the need of using apex locators rather than relying on radiographs for canal length determination. These findings also support the current practice of cutting 3 mm of the root apex (Kim & Kratchman 2006) during surgical procedures to ensure the removal of most of the unprepared and unfilled canals.

Unlike most of the previous studies mesial and mesiobuccal roots of mandibular and maxillary molars respectively had a higher frequency of single foramen. This may be interpreted that there was a high tendency for Type II (two canals merging into one at apex) canals

	Minimum	Maximum	Average	SD
Mandibular teeth				
First premolar	0.064	0.512	0.173	0.074
Second premolar	0.06	0.439	0.158	0.065
First molar: mesial root	0.065	0.495	0.178	0.078
First molar: distal root	0.074	0.544	0.222	0.084
Second molar: mesial root	0.061	0.654	0.198	0.098
Second molar: distal root	0.101	0.581	0.227	0.083
Maxillary teeth				
First premolar	0.059	0.493	0.171	0.064
Second premolar	0.032	0.406	0.169	0.068
First molar: mesiobuccal root	0.045	0.428	0.174	0.068
First molar: distobuccal root	0.043	0.398	0.183	0.069
First molar: palatal root	0.073	0.714	0.226	0.108
Second molar: mesiobuccal root	0.045	0.422	0.168	0.07
Second molar: distobuccal root	0.052	0.387	0.171	0.07
Second molar: palatal root	0.065	0.506	0.218	0.087

Table 5 Minimum diameter (in mm) ofminor apical foramina by tooth type



Figure 4 Photomicrograph of maxillary second premolar $(40\times)$, with five minor apical foramina and one accessory foramen, identified by regulating the focus.

in mesial/mesiobuccal roots in this north Indian population. This anatomy is best treated by preparing and filling the straighter canal (generally palatal/ lingual) to the apex and the other (buccal) canal to point of juncture. If both canals are enlarged to the apex, an 'hour glass' preparation results, which leaves voids in apical third during filling (Vertucci 2005).

The presence of two root canals with two apical foramina in the palatal root of maxillary molars is uncommon. However, the present study revealed that approximately 20% of palatal roots of maxillary first molars and 11% of maxillary second molars had two minor apical foramina of similar dimensions. About 2% and 1% palatal roots of maxillary first and second molars, respectively, had three foramina. This finding

may indicate the presence of two or more root canals or one root canal with an apical ramification in the palatal roots of maxillary molars. Up to five apical foramina were observed in 0.75% samples in mandibular and maxillary premolars and mesial and mesiobuccal roots of first molars similar to the study of Gutierrez & Aguayo (1995). There was a high frequency of accessory foramina in both maxillary and mandibular premolars amongst all tooth type; supporting the findings of Morfis et al. (1994) that maxillary and mandibular premolars have the most complicated apical morphologic make up with respect to main foramina and accessory foramina. A high frequency of accessory foramina as well as multiple foramina suggests the extensive branching of the root canal or the presence of multiple canals at the apex and thus relates to high incidence of post-treatment apical periodontitis (Green et al. 1997, Barthel et al. 2004) due to non negotiation of extra canals by orthograde instrumentation alone and further suggests scope of surgical endodontics for management of such teeth.

The mean maximum diameter of the minor apical foramina ranged from 0.23 to 0.32 mm and the mean minimum diameter was in the range 0.158–0.227 mm. These values were in accordance with Marroquin *et al.* (2004) (0.20–0.29 mm), Cheung *et al.* (2007) (0.32 mm) and Wu *et al.* (2000) (0.13–0.46 mm) but lower than those reported by Morfis *et al.* (0.418–0.977 mm) and by Gani & Visvisian (0.332–0.594 mm). These results support that instrument sizes 10 or 15 often do not have contact at the minor apical foramen but rather encounter resistance elsewhere because of root canal irregularities or

curvature. So, in this Indian population the first file that will truly bind at the apex, i.e. initial working width at working length would correspond to at least a size 20 file.

The most common shape of the minor apical foramen was oval. The frequencies were between 79% and 89% for various roots. This prevalence of oval canals were higher than Marroquin *et al.* (2004) and Wu *et al.* (2000) and lower than Gani & Visvisian (1999). Other forms of apical foramina such as triangular, kidney, or irregular forms were observed in 0.5% of the roots (Fig. 5).

One of the major point of interest when planning this investigation was its clinical significance when shaping and cleaning the root canal of this Indian population. The determination of the first file that binds in the apical part of the root canal does not allow a reliable prediction of the appropriate final instrument size required for complete apical enlargement. The final instrument size must be large enough to touch all walls. Because most canals are oval in their cross sectional shape, the goal should be to make the final apical instrument size correspond to the largest diameter of the oval to make these canals round. The difference between the wide and narrow diameters of the apical constriction region in mandibular premolars in this population, was less than or equal to 0.15 mm in 86% teeth therefore enlarging up to three instrument sizes larger than the first binding file in apical constriction region (FAB) will shape the minor apical foramen area round only in 86% teeth. This difference between the wide and narrow diameters in these premolars was less than or equal to 0.20 mm in 91%



Figure 5 Minor apical foramina of various irregular shapes (irregular, kidney shaped, triangular).

and less than or equal to 0.25 mm in 97% teeth so shaping up to 4 instrument sizes larger than FAB will shape apical area in 91% and five instrument size larger than FAB will shape the apical area in 97% teeth to a round outline. Similarly, for the rest of the teeth it was found that up to three instrument sizes larger than FAB would shape the apical constriction round in only 84% of mandibular molars, 88% of maxillary premolars and 87% of maxillary molars. While four instrument sizes larger than FAB will shape apical constriction round in 89% of mandibular molars, 93% of maxillary premolars and 94% of maxillary molars, and five instrument sizes larger than the FAB will shape apical constriction round in 94% of mandibular molars, 97% of maxillary premolars and 96% of maxillary molars. These findings suggest that in the absence of any predictable method to measure accurate working width, enlargement of apical third 4-5 sizes larger than first file to bind at the apex may ensure complete involvement of the largest diameter of an oval canal in more than 95% teeth and will produce a round shape of apical preparation for proper filling with a round gutta percha cone.

Conclusions

The incidence of oval canals was higher in this Indian population (81%) compared to other populations and occurred in 79–88% of roots depending on tooth type. In 92% and 96% of teeth the difference between the maximum and the minimum diameter of all foramina was less than or equal to 0.20 and 0.25 mm, respectively, therefore four to five instrument sizes larger than the first binding file would have been necessary to shape the minor apical foramen of more than 95% of the teeth included in this study to make them round.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Mandibular First Premolar.

Table S2. Mandibular Second Premolar.

Table S3. Mandibular First Molar Mesial Root.

Table S4. Mandibular First Molar Distal Root.

 Table S5. Mandibular Second Molar Mesial Root.

Table S6. Mandibular Second Molar Distal Root.

Table S7. Maxillary First Premolar.

Table S8. Maxillary Second Premolar.

 Table S9. Maxillary First Molar (Mesiobuccal Root).

Table S10. Maxillary First Molar (Distobuccal Root).

 $\label{eq:sigma} \textbf{Table S11.} \ \textbf{Maxillary First Molar (Palatal Root).}$

 Table S12.
 Maxillary Second Molar (Mesiobuccal Root).

 Table S13. Maxillary Second Molar (Distobuccal Root).

Table S14. Maxillary Second Molar (Palatal Root).**Table S15.** Maximum diameter (in mm) of accessoryforamina by tooth type.

Table S16. Minimum diameter (in mm) of accessory foramina by tooth type.

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