Acta Odontologica Scandinavica. 2015; 73: 101–106

informa healthcare

ORIGINAL ARTICLE

Influence of tooth length on the accuracy of the Root ZX electronic apical foramen locator: An *ex vivo* study

MASOUD SAATCHI[1], IMAN RAHIMI[1], ABBASALI KHADEMI[1], ALI REZA FARHAD[1], MOHAMMAD HOSSEIN NEKOOFAR[2,3] & PAUL MH DUMMER[3]

[1]*Torabinejad Dental Research Center, Department of Endodontics, School of Dentistry, Isfahan University of Medical Sciences, Isfahan, Iran,* [2]*Department of Endodontics, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran, and* [3]*Endodontology Research Group, School of Dentistry, College of Biomedical and Life Sciences, Cardiff University, Cardiff, UK*

Abstract

Objective. Electronic apical foramen locators are now widely used to determine working length. This study was designed to determine whether tooth length influenced the accuracy of the Root ZX device. ***Materials and methods.*** Forty extracted maxillary canine teeth with a length range of 27–29 mm were selected. Access cavities were prepared and coronal flaring of canals performed. The teeth were mounted in self-polymerizing acrylic resin to facilitate horizontal sectioning except for the apical 3–4-mm portion of the root and embedded in alginate as the electronic medium. Electronic measurements were taken at the major foramen, 'zero' reading using the Root ZX and compared with the actual root canal length. The teeth were sectioned 3 mm from the coronal reference point to create a second group with shorter length; these reductions in the length continued six times in all to create seven groups of 40 specimens each. The actual and electronic lengths of specimens in each group were measured. Data were analyzed by Pearson's correlation coefficient. ***Results.*** Identical measurements between the actual and electronic root canal length from the longest to the shortest groups were 12.5%, 10.0%, 20.0%, 27.5%, 37.5%, 35.0% and 45.0%, respectively. There was a mild negative correlation between the precise measurements of the Root ZX and root canal lengths in the seven groups ($r = -0.964$, $p < 0.001$). ***Conclusion.*** Under the conditions of the study, the Root ZX device was more accurate in shorter teeth compared to longer ones.

Key Words: *Apical foramen, electronic apex locators, Root ZX, tooth length, working length*

Introduction

Working length (WL), the distance from a coronal reference point to the point at which canal preparation and filling should terminate, is one of the crucial factors that must be managed for successful root canal treatment [1]. Ideally, the apical limit of canal preparation should be at the canal terminus, which is regarded by most clinicians as the minor foramen. Under-estimation of WL may cause insufficient debridement of root canal systems and residual intra-canal infection, whereas over-estimation of WL may interfere with healing processes through chemical, biological and mechanical irritation of periapical tissues [2–4]. Optimal healing conditions occur when the filling material is in minimal contact with apical tissues [4].

WL has been commonly determined by radiographic and/or electronic methods [1]. Radiographic methods are not reliable because it is impossible to identify the exact location of the canal terminus, particularly since the apical foramen often deviates to the side of the root and emerges at various distances from the anatomic apex [5]. In addition, radiographs can be influenced by superimposition of anatomical and bony structures, cone angulations and tooth inclination, which can consequently lead to magnification and image distortion [6]. On clinical radiographs when a file was estimated to be short of the canal terminus using the bisecting angle or paralleling

Correspondence: Dr Iman Rahimi, Torabinejad Dental Research Center, Department of Endodontics, School of Dentistry, Isfahan University of Medical Sciences, Isfahan, Zip Code: 81746-73461, Iran. Tel: +0098 311 792 28 22. Fax: +0098 311 668 70 80. E-mail: iman.ra13@gmail.com

(Received 17 November 2013; accepted 7 August 2014)

ISSN 0001-6357 print/ISSN 1502-3850 online © 2015 Informa Healthcare
DOI: 10.3109/00016357.2014.956144

techniques, they were actually extended past the foramen in 33% and 20% of cases, respectively [7]. Other disadvantages of the radiographic method are hazards associated with ionizing radiation, technical errors and the fact it is time-consuming [8].

Electronic methods of measuring tooth length were first proposed by Custer [9]. Later Suzuki [10] discovered a constant electrical resistance value of 6.5 kΩ between the periodontal ligament and the oral mucosa. Sunada [11] then applied the principle to clinical practice and developed the first electronic apical foramen locators. Since then, a variety of other operating principles and electronic methods have been developed and various electronic devices have been introduced [12]. Obviously, these devices do not assess the position of the root apex and it is unfortunate that they are generally called electronic apex locators. Thus, use of the generic name electronic apical foramen locator (EAFL) may be more appropriate [13].

The first EAFLs had shortcomings in relation to poor accuracy in the presence of electrolytes and the need for calibration, which was overcome by subsequent devices [14]. The Root ZX (J. Morita Corp., Tokyo, Japan) measures the impedance ratio of two different frequencies to indicate the location of the file tip in the canal, regardless of the type of electrolyte, and requires no calibration [15].

The effects of various factors, such as file diameter [16], file alloy [17,18], tooth type [19], EAFL type [20], apical foramen diameter [16], root canal diameter [21], pulp vitality [22], root resorption [23], root fracture [24], apical periodontitis [25], irrigant solution [26] and endodontic retreatment [27], on the accuracy of EAFLs have been evaluated. Moreover, file interference within the root canal space is another factor, which can influence the accuracy of EAFLs. For example, it has been shown that flaring of the cervical and middle thirds of the root canal and elimination of interferences in these regions allow for more accurate readings by EAFLs [28,29]. A file is likely to be constrained and/or more in contact with dentine within long canals than short ones when reaching the canal terminus. Therefore, variations in tooth length may affect the accuracy of EAFLs. There are no studies available on the influence of tooth length, as a potential interfering factor, on the function of EAFLs. Thus, the aim of this *ex vivo* study was to evaluate the influence of tooth length on the accuracy of a commonly used EAFL, the Root ZX.

Materials and methods

Forty extracted human maxillary canine teeth between 27–29 mm long were selected. The teeth were soaked in 5.25% sodium hypochlorite for 3 h and rinsed with tap water for 5 min to remove remnants of periodontal tissue. All the teeth were checked for external cracks, open apices, restorations, root resorptions or previous root canal treatment; teeth with any of these characteristics were excluded.

Conventional access cavities were prepared with a number 1014 round diamond bur (KG, Sorensen, Sao Paulo, SP, Brazil) and finished with an Endo Z bur (Dentsply Maillefer, Ballaigues, Switzerland) under continuous water spray. The incisal edges were ground with the same bur to create a flat surface to provide a stable reference point. Remnants of pulp tissue and debris were removed with sizes 10 and 15 K-files (Dentsply Maillefer). The coronal one-third of each canal was flared with sizes 2, 3 and 4 Gates-Glidden burs. The canals were irrigated with 2.5% sodium hypochlorite solution and normal saline using a 27-gauge needle after each instrument. The patency of the apical foramen was confirmed with a size 10 K-file. The tooth was mounted in self-polymerizing acrylic resin (Vertex, Zeist, the Netherlands) to facilitate sectioning except for the apical 3–4 mm of the root, which was then embedded in alginate (Figure 1). In order to regain the access cavity through the acrylic resin, a cotton pellet followed by a wax build up was placed. Actual and electronic root canal length were determined by an experienced endodontist, similar to the technique used by Herrera et al. [16].

Based on the size of canal, the actual root canal length was determined by inserting a size 10 or 15 K-file into the canal until the file tip was just visible at the major foramen under a surgical microscope (OPMI Primo, Carl Zeiss, Oberkochen, Germany) at ×16 magnification. The silicone stop was adjusted to the

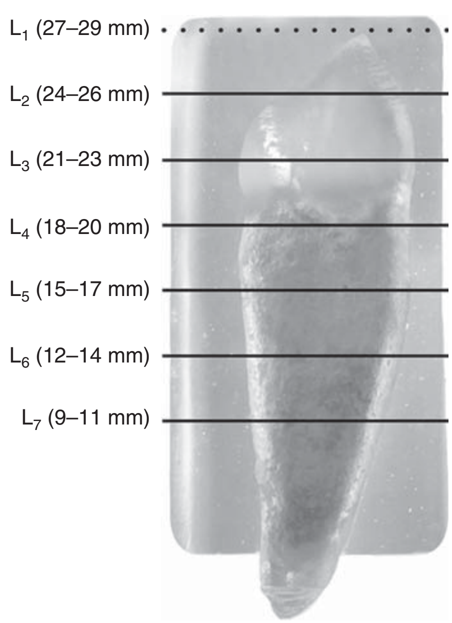

Figure 1. A mounted tooth in self-polymerizing acrylic resin was horizontally sectioned at 3-mm intervals from the coronal reference point.2 The reduction continued up to six sections to attain seven length levels.

Table I. Number (percentage) of the differences between electronically determined and actual length in the seven length groups.

EL-AL (mm)	L_1 27–29	L_2 24–26	L_3 21–23	L_4 18–20	L_5 15–17	L_6 12–14	L_7 9–11
> 0.5	0 (0.0)	0 (0.0)	0 (0.0)	1 (2.5)	0 (0.0)	1 (2.5)	0 (0.0)
0.01–0.5	2 (5.0)	2 (5.0)	7 (17.5)	3 (7.5)	3 (7.5)	9 (22.5)	10 (25.5)
0.00	5 (12.5)	4 (10.0)	8 (20.0)	11 (27.5)	15 (37.5)	14 (35.0)	18 (45.0)
−0.5–−0.01	14 (35)	19 (47.5)	14 (35.0)	14 (35.0)	13 (32.5)	10 (25.0)	8 (20.0)
< −0.5	19 (47.5)	14 (35.0)	11 (27.5)	11 (27.5)	9 (22.5)	6 (15.0)	4 (10.0)

EL-AL: Electronic length minus actual length; L: length group (mm).

level of the reference point, the file removed and the distance from the silicone stop to the file tip was recorded with an endodontic ruler to the nearest 0.25 mm under ×3 magnification using binocular loupes (Heine, Herrsching, Germany).

The electronic length was determined with each specimen mounted in a modified polyethylene box containing alginate (Alginoplast; Heraeus-Kulzer, Hanau, Germany) as described by Baldi et al. [30]. Two orifices were made in the lids, one in the center for placing the tooth and the other laterally for placing the lip electrode. The root canals were irrigated with normal saline and the excess removed from the pulp chamber using a cotton pellet. The lip electrode was immersed in the respective orifice in the lid, coming into contact with the alginate at a distance of ~ 9 mm from the root apex; a 31 mm size 10 or 15 K-file was then connected to the file electrode for electronic measurement. The file was inserted into the canal until the visual display indicated the reading of 'APEX', zero reading, and there was a continuous audible signal indicating major foramen [31]. The attachment position of the file electrode was then adjusted to be 1–3 mm above the coronal reference point and the silicone stop was placed in close contact with the reference point. Afterwards the file was removed and the distance from the silicone stop to the file tip was measured. The measurements were categorized as exactly correct and within a tolerance limit of ± 0.5.

All the teeth (ranging from 27–29 mm in length) were sectioned horizontal 3 mm from the coronal reference point to reduce their length by 3 mm to create a second experimental group of the same 40 teeth (ranging from 24–26 mm in length). The sections were made with a water-cooled, slow-speed diamond saw sectioning machine. In the same manner, reductions in the length by 3-mm continued up to 6-times with electronic and actual root canal length measurements taken at each stage. Therefore, there were seven groups with 40 specimens in each group, as outlined in Figure 1. The actual and electronic root canal lengths in each group were calculated as described previously. All the actual and electronic measurements were made in triplicate and the mean value of the three readings was recorded as the result. In each specimen, the actual root canal length was then subtracted from the electronic measurement. Positive values indicated measurements exceeding the major foramen (long); however, negative values indicated measurements short of the major foramen.

Data were then subjected to statistical analysis using SPSS software, version 15 (SPSS Inc, Chicago, IL). The percentage and the corresponding 95% confidence interval (CI) of the exact measurements and within the error range of ± 0.5 mm were calculated for all groups. Statistical analysis was carried out by the Pearson's correlation coefficient. The correlation between the precise measurements and the root canal lengths in the seven length groups was analyzed. In addition, the correlation between the electronic measurements within the 0.5 mm tolerance and the root canal lengths in the groups was analyzed.

Results

Table I shows the position of the file tip as determined electronically relative to the actual root canal length in all groups. Table II shows the percentage and corresponding 95% CI of the exact measurements and within the error range of ± 0.5 mm for the groups.

Table II. Percentage and corresponding 95% CI of the exact measurements and within the error range of ± 0.5 mm for the length groups.

	Exact measurement		± 0.5 mm tolerance	
Group (mm)	%	95% CI	%	95% CI
L1 (27–29)	12.5	2.3–22.8	52.5	37.0–68.0
L2 (24–26)	10.0	0.7–19.0	62.5	47.5–77.5
L3 (21–23)	20.0	7.6–32.4	72.5	58.7–86.3
L4 (18–20)	27.5	13.7–41.3	70.0	55.8–84.2
L5 (15–17)	37.5	22.5–52.5	77.5	64.6–90.4
L6 (12–14)	35.0	20.2–49.8	82.5	70.7–94.3
L7 (9–11)	45.0	29.6–60.4	90.5	80.7–99.3

L: length group; CI: confidence interval.

There was a mild negative correlation between the measurements of the EAFL and the root canal lengths in the seven length groups for the exact measurements ($r = -0.964$, $p < 0.001$) and within the error range of ± 0.5 mm ($r = -0.975$, $p < 0.001$).

Discussion

It has been reported that the accuracy of EAFLs in determining the working length is 31–100% [1,32,33]. de Camargo et al. [28] and Ibarrola et al. [29] observed a better performance of the Root ZX in canals following coronal enlargement. They reported that this might be attributed to the elimination of interferences from the cervical dentin. Briseño-Marroquín et al. [33] and Nguyen et al. [34] reported that accuracy of the EAFLs is not influenced by the file size. However, Briseño-Marroquín et al. observed a tendency to make unstable measurements with file size 15 which could be explained as a result of the higher friction experienced by this file in root canals with a relatively small diameter. Ebrahim et al. [35] claimed electronic root canal measurements performed in an enlarged canal were inaccurate using small files. Vasconcelos et al. [36] reported the accuracy of Root ZX improved significantly when the precisely fit apical file was used. Herrera et al. [37] claimed that the precision of EAFLs might be influenced by file size as smaller files leave space inside the canal whereas larger files fit more tightly. Thus, file constraint and interference within the root canal space may influence the accuracy of EAFLs.

Tooth length is another factor which may affect file interference within the root canal. Maxillary canines are the longest teeth with an average length of 26.5 mm, whereas maxillary third molars are the shortest teeth with an average length of 17 mm [38]. Furthermore, tooth surface loss can reduce tooth length. Since the aim of this study was to evaluate the influence of tooth length on the accuracy of the EAFL, maxillary canines were used as the longest teeth in the mouth as they could be reduced in length incrementally to create shorter teeth.

To eliminate confounding factors, including apical foramen diameter, canal diameter, canal curvature and to make the groups as homogeneous as possible, the same teeth were used throughout and in each length category by gradual length reduction instead of using different teeth with a wide range of lengths.

Baldi et al. [30] compared alginate, gelatin, saline, sponge and agar as embedding media in the evaluation of the accuracy of EAFLs. They reported no significant differences between the media used. However, alginate provided the most coherent results, therefore, in the present study alginate was used as the embedding medium.

Evidence has shown that the accuracy of EAFLs was not affected by the commonly used irrigation solutions such as chlorhexidine, EDTA, normal saline and sodium hypochlorite [1,39,40]. However, we used sodium hypochlorite during the coronal enlargement and normal saline during the electronic root canal length measurement.

The position of the apical constriction or minor foramen and its relationship with the CDJ are irregular [5,13,41]. Ounsi and Naaman [42] concluded 'the Root ZX is not capable of detecting the "0.5 mm from the foramen" position and, thus, should only be used to detect the foramen (major diameter)'. Therefore, the practitioner will be able to choose the apical safety margin required for canal preparation. Different apical reference points and experimental protocols have been established to evaluate the accuracy of EAFLs. The major foramen is more consistent and is a better landmark to test for EAFLs accuracy [43]. Some studies considered the major foramen as a reproducible apical reference point [19,28,44]. Consideration of the major foramen as the apical reference point does not mean that the working length should terminated at that point. It just means that the major foramen was considered as a better apical landmark to evaluate the accuracy of EAFLs. Thus, the major foramen was the preferred apical reference point for the actual root canal length measurements and the 'APEX' mark on the Root ZX display was used during the electronic measurements. The overall precision of the Root ZX was 26.79%; that is, with perfect agreement between the actual and electronic readings. This is consistent with the results of other studies reporting the proportion of exact measurements with the EAFL [16,33]. However, 72.86%.of electronic measurements were within ± 0.5 mm of the actual root canal length.

Overall, the accuracy of the EAFL increased gradually with sequential tooth length reduction. The percentage of precise measurements was 12.5% in the L_1 group (27–29 mm) and 45% in the L_7 group (9–11 mm). That is it increased by 32.5% from the L_7 group to the L_1 group confirming the negative correlation between the accuracy of the EAFL and root canal length.

Positive values mean that the file extended through the major foramen, whereas negative values meant the file tip was positioned short of the major foramen. In this study, a high tendency toward negative values was observed and, thus, the majority of the electronic readings were short of the actual length. Also of interest was the specific pattern of distribution for the measurements among the length groups. The high numbers of the negative values in the longest teeth were gradually shifted into positive values during subsequent length reduction. That is, there was a tendency for long teeth to be associated with file tips short of the foramen.

Duran-Sindreu et al. [45] demonstrated no statistically significant differences in the accuracy of Root

ZX device between *in vivo* and *in vitro* models. However, some limitations of *in vitro* studies in evaluation of EAFLs are inaccurate adjustment of the rubber stop to the reference point or possible movement of the rubber stop during the measurement procedure. In this study, to minimize the procedural errors, eliminate the confounding factors and increase the reliability of the study, the teeth were flattened incisally to provide a stable coronal reference point; the rubber stop was carefully adjusted to the reference level with the aid of $\times 3$ magnification binocular loupes. Another limitation of this study was that re-insertions of file into the canal could have enlarged the apical foramen and may have an effect on the accuracy the EAFL.

Under the conditions of the present study, the accuracy of the Root ZX was influenced by tooth length. The EAFL provided higher accuracy in short teeth compared to longer ones.

Acknowledgements

This study was supported by Isfahan University of Medical Sciences Research Grant # 391111. We would like to thank Dr Bahram Soleimani for statistical consultation.

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

References

[1] Gordon MP, Chandler NP. Electronic apex locators. Int Endod J 2004;37:425–37.
[2] Ricucci D. Apical limit of root canal instrumentation and obturation, part 1. Literature review. Int Endod J 1998;31: 384–93.
[3] Ayranci LB, Yeter KY, Arslan H, Kseoglu M. Morphology of apical foramen in permanent molars and premolars in a Turkish population. Acta Odontol Scand 2013;71:1043–9.
[4] Sjogren U, Hagglund B, Sundqvist G, Wing K. Factors affecting the long-term results of endodontic treatment. J Endod 1990;16:498–504.
[5] Dummer PM, McGinn JH, Rees DG. The position and topography of the apical canal constriction and apical foramen. Int Endod J 1984;17:192–8.
[6] Tamse A, Kaffe I, Fishel D. Zygomatic arch interference with correct radiographic diagnosis in maxillary molar endodontics. Oral Surg Oral Med Oral Pathol 1980;50:563–6.
[7] Chunn CB, Zardiackas LD, Menke RA. *In vivo* root canal length determination using the Forameter. J Endod 1981;7: 505–20.
[8] Heling B, Karmon A. Determining tooth length with bisecting angle radiographs. J Br Endod Soc 1976;9:75–9.
[9] Custer L. Exact methods of locating the apical foramen. J Natl Dent Assoc 1918;5:815–19.
[10] Suzuki K. Experimental study on iontophoresis. J Jpn Stomatol 1942;16:411.
[11] Sunada I. New method for measuring the length of the root canal. J Dent Res 1962;41:375–87.
[12] Moscoso S, Pineda K, Basilio J, Alvarado C, Roig M, Duran-Sindreu F. Evaluation of dentaport ZX and raypex 6 electronic apex locators: an in vivo study. Med Oral Patol Oral Cir Bucal 2014;19:e202–5.
[13] Nekoofar MH, Ghandi MM, Hayes SJ, Dummer PM. The fundamental operating principles of electronic root canal length measurement devices. Int Endod J 2006;39:595–609.
[14] Kim E, Lee SJ. Electronic apex locator. Dent Clin North Am 2004;48:35–54.
[15] Kobayashi C, Suda H. New electronic canal measuring device based on the ratio method. J Endod 1994;20:111–14.
[16] Herrera M, Abalos C, Lucena C, Jimenez-Planas A, Llamas R. Critical diameter of apical foramen and of file size using the Root ZX apex locator: an in vitro study. J Endod 2011;37:1306–9.
[17] Sadeghi S, Abolghasemi M. The accuracy of the Raypex5 electronic apex locator using stainless-steel hand K-file versus nickel-titanium rotary Mtwo file. Med Oral Patol Oral Cir Bucal 2010;15:e788–90.
[18] Nekoofar MH, Sadeghi K, Sadighi Akha E, Namazikhah MS. The accuracy of the Neosono Ultima EZ apex locator using files of different alloys: an in vitro study. J Calif Dent Assoc 2002;30:681–4.
[19] Mancini M, Felici R, Conte G, Costantini M, Cianconi L. Accuracy of three electronic apex locators in anterior and posterior teeth: an ex vivo study. J Endod 2011;37:684–7.
[20] Vieyra JP, Acosta J. Comparison of working length determination with radiographs and four electronic apex locators. Int Endod J 2011;44:510–18.
[21] Ebrahim AK, Wadachi R, Suda H. An in vitro evaluation of the accuracy of Dentaport ZX apex locator in enlarged root canals. Aust Dent J 2007;52:193–7.
[22] Akisue E, Gavini G, de Figueiredo JA. Influence of pulp vitality on length determination by using the Elements Diagnostic Unit and Apex Locator. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;104:e129–32.
[23] Goldberg F, De Silvio AC, Manfre S, Nastri N. In vitro measurement accuracy of an electronic apex locator in teeth with simulated apical root resorption. J Endod 2002;28:461–3.
[24] Goldberg F, Frajlich S, Kuttler S, Manzur E, Briseno-Marroquin B. The evaluation of four electronic apex locators in teeth with simulated horizontal oblique root fractures. J Endod 2008;34:1497–9.
[25] Saatchi M, Aminozarbian MG, Hasheminia SM, Mortaheb A. Influence of apical periodontitis on the accuracy of 3 electronic root canal length measurement devices: an in vivo study. J Endod 2014;40:335–9.
[26] Carvalho AL, Moura-Netto C, Moura AA, Marques MM, Davidowicz H. Accuracy of three electronic apex locators in the presence of different irrigating solutions. Braz Oral Res 2010;24:394–8.
[27] Goldberg F, Marroquin BB, Frajlich S, Dreyer C. In vitro evaluation of the ability of three apex locators to determine the working length during retreatment. J Endod 2005;31:676–8.
[28] de Camargo EJ, Zapata RO, Medeiros PL, Bramante CM, Bernardineli N, Garcia RB, et al. Influence of preflaring on the accuracy of length determination with four electronic apex locators. J Endod 2009;35:1300–2.
[29] Ibarrola JL, Chapman BL, Howard JH, Knowles KI, Ludlow MO. Effect of preflaring on Root ZX apex locators. J Endod 1999;25:625–6.
[30] Baldi JV, Victorino FR, Bernardes RA, de Moraes IG, Bramante CM, Garcia RB, et al. Influence of embedding media on the assessment of electronic apex locators. J Endod 2007;33:476–9.
[31] Jung IY, Yoon BH, Lee SJ. Comparison of the reliability of 0.5 and APEX mark measurements in two frequency-based electronic apex locators. J Endod 2011;37:49–52.
[32] Pascon EA, Marrelli M, Congi O, Ciancio R, Miceli F, Versiani MA. An ex vivo comparison of working length

determination by 3 electronic apex locators. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:e147–51.

[33] Briseno-Marroquin B, Frajlich S, Goldberg F, Willershausen B. Influence of instrument size on the accuracy of different apex locators: an in vitro study. J Endod 2008;34:698–702.

[34] Nguyen H, Kaufman A, Komorowski R, Friedman S. Electronic length measurement using small and large files in enlarged canals. Int Endod J 1996;29:359–64.

[35] Ebrahim AK, Yoshioka T, Kobayashi C, Suda H. The effects of file size, sodium hypochlorite and blood on the accuracy of Root ZX apex locator in enlarged root canals: an in vitro study. Aust Dent J 2006;51:153–7.

[36] Vasconcelos BC, Matos Lde A, Pinheiro-Junior EC, Menezes AS, Vivacqua-Gomes N. Ex vivo accuracy of three electronic apex locators using different apical file sizes. Braz Dent J 2012;23:199–204.

[37] Herrera M, Abalos C, Planas AJ, Llamas R. Influence of apical constriction diameter on Root ZX apex locator precision. J Endod 2007;33:995–8.

[38] Vertucci F, Haddix JE. Tooth morphology and access cavity preparation. In Hargreaves KM, Cohen S. Cohen's pathways of the pulp, 10th edition. Mosby; St. Louis, MO: 2011: 136–222.

[39] Duran-Sindreu F, Gomes S, Stober E, Mercade M, Jane L, Roig M. In vivo evaluation of the iPex and Root ZX electronic apex locators using various irrigants. Int Endod J 2012;46: 769–74.

[40] Gomes S, Oliver R, Macouzet C, Mercade M, Roig M, Duran-Sindreu F. In vivo evaluation of the Raypex 5 by using different irrigants. J Endod 2012;38:1075–7.

[41] Ricucci D, Langeland K. Apical limit of root canal instrumentation and obturation, part 2. A histological study. Int Endod J 1998;31:394–409.

[42] Ounsi HF, Naaman A. In vitro evaluation of the reliability of the Root ZX electronic apex locator. Int Endod J 1999;32:120–3.

[43] Lee SJ, Nam KC, Kim YJ, Kim DW. Clinical accuracy of a new apex locator with an automatic compensation circuit. J Endod 2002;28:706–9.

[44] Venturi M, Breschi L. A comparison between two electronic apex locators: an in vivo investigation. Int Endod J 2004;38: 36–45.

[45] Duran-Sindreu F, Stober E, Mercade M, Vera J, Garcia M, Bueno R, et al. Comparison of in vivo and in vitro readings when testing the accuracy of the Root ZX apex locator. J Endod 2012;38:236–9.