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Research Article

Comparison of the Precision with Five EALs: RootZX, Apex ID, Raypex 6, Mini Apex Locator and Canal Pro for Establishing Working Length as Related to Digital Radiographs

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Abstract

Aim: The goal of this research was to assess in vivo the precision of five EALs to establishing working length as related to digital radiographs: RootZX, Apex ID, Raypex 6, Mini Apex Locator and Canal Pro at levels 1 mm short of the apical foramen (-1.0), followed by measurements at (-0.5), (0.0), (+ 0.5) and (+1.0).

Methods: 120 patients (247 canals) participated in the study. Electronic measurements were performed 1 mm short of the apical foramen (-1.0), followed by measurements at (-0.5), (0.0), (+ 0.5) and (+1.0). The dimensions found by the five EALs and radiographs relative to the actual position of the AC were related using a paired samples t exam, X^2 test.

Results: For front teeth, EALs and radiographs found the minor foramen 88.05%, 83.6%, 83.6%, 80.6% and 52.2% of the time, respectively. For bicuspid teeth, EALs and radiographs located the minor foramen 93.75%, 87.5%, 93.7%, 87.5% and 37.5% of the time, respectively. For posterior teeth, the Root ZX, EALs and radiographs located the minor foramen 83.78%, 81.08%, 63%, 83.78%, 78.37% and 21.62% of the time, respectively. There was no statistically significant difference between the four EALs but there was a difference bet the EALs and radiographs. p = 0.05.

Conclusions: Under the clinical scenario presented the EALs identified the minor foramen with a great grade of precision. EALs were more precise, related to radiographs with the potential to significantly decrease the risk of instrumenting and filling outside the apical foramen. The study revealed that use EALs are safe and secure.

Keywords: *Apex Locator; Working Length; Apical Foramen; Apical Constriction*

Introduction

Complete removal of pulp tissue, organic and inorganic material from the root canal (RC) space is critical for root canal treatment (RCT) success. Is important to consider the length and width of the canal, knowing this dimension's clinicians can properly fill the canals and not extend outside the tooth apex. The apical constriction, is a reasonable site for establishing working length (WL) it frequently corresponds with the constricted width of the RC [1,2]. Dummer., *et al.* [3] established that it is tough to localize the apical constriction *in vivo* with reliance because of its situation and topographic structure.

The cementodentinal junction (CDJ) has been recommended as the histological site for WL because it denotes the transition among two tissues [4]. The location of the CDJ is commonly recognized as located 0.50 mm - 0.75 mm cervical to the minor foramen [5]. Frequently, the CDJ is careful to be co-located with the minor foramen [6]; nonetheless, this is not all the time the occasion [3].

WL is termed as "the distance from a coronal reference point to the point at which canal preparation and filling should terminate" [2]. The radiographic position of WL has restrictions that complicate its interpretation and reading. Once a radiographic technique is recommended alterations of structures has been encountered to be around 5% [7]. Precise ubication of WL using the apical constriction or the apical foramen as orientations is an exceptionally significant issue for the achievement of endodontic treatments.

Variations in determine the WL finish in alterations due to the variations in distance among the apical foramen and the radiographic apex [8].

Procedures of calculating the WL comprise tactile feeling, information of RC lengths, appraisal of pre-operative Xrays, and EALs [9]. Periapical films have been selected as the conventional and suitable manner of obtaining evidence on the configuration of the RC and its adjacent tissues [10]. Digital radiography still has limitations [9].

Periapical films are essential tools for analysis, for working films (e.g. calculating the WL of RC, fitting gutta percha cones), to confirm the final obturation, and for follow-up comparisons. The development and production of electronic devices for locating the canal terminus have been a revolutionizing innovation in root canal treatment.

Custer [11] and Suzuki [12] determined WL electronically and examined the electrical characteristics of oral structures and developing the first electronic apex locator. The electronic apex locators (EALs) were resistance-based and calculated the resistance among 2 electrical terminals to define the position of an instrument inside the canal. Later EALs were impedance-based [13] and employed various frequencies.

The mechanism of EALs established on the source of frequency reliant on impedance, EALs have been reliable with the basic role in determining the root canal length. Though even operating the similar norm, modern EALs manage fine internal procedures that vary from the initially suggested ones.

Several devices employ the impedance quotient source such as Root ZX (0.4 - 8 kHz) (J. Morita, Tokyo, Japan) [14,15] and Apex ID (0.5 - 5 kHz) (SybronEndo, Glendora, USA) (16, 17). Raypex 6 (0.4 - 8 kHz) (VDW GmbH, Munich, Germany) (18), Mini Apex Locator (SybronEndo, Glendora, USA) that operating as a two frequency-based measurement system that emits an all-digital signal, which according to its manufacturers, leads to improved precision and CanalPro (Coltene Whaledent, Inc.), a modern apex locator uses multiple frequencies (unlike conventional apex locators, two measuring frequencies are alternated, not mixed, eliminating noise and the need for signal filtering. Signal intensity is used to calculate the file tip position, making the measurement immune to electromagnetic interference) in an attempt to eliminate the influence of canal conditions [19].

EALs have the potential to facilitate the position of the instrument inside the RC, permitting more accurate *in vivo* establishment of WL [20]. Many studies have addressed the benefits and clinical performance of the many different models of EALs that have been developed in recent years with great consistency and high accuracy and in finding the major foramen regardless of the internal environment [21].

EALs have the capacity to moderate the number of radiographs used through root canal therapy [22]. Current EALs can detect the apical foramen and the apical constriction with extraordinary precision. The accuracy of depth might also fluctuate on the file size and the anatomy of RC [23].

Therefore, the goal of this research is to assess *in vivo* the precision of five EALs: RootZX, Apex ID, Raypex 6, Mini Apex Locator and Canal Pro for establish working length as related to digital radiographs at levels 1mm short of the apical foramen (-1.0), followed by measurements at (-0.5), (0.0), (+ 0.5) and (+1.0). The null hypothesis considered was that no major dissimilarities would be encountered between the five EALs.

Materials and Methods

This clinical study was achieved at the Universidad Autónoma de Baja California, School of Dentistry, Tijuana, Mexico. The study protocol was accepted by the Ethics Committee (87/2018) and conducted in agreement with the ethical principles of the last update of the Declaration of Helsinki [24]. All participants were informed on the goals and strategy of the study and written informed consent permissions were gained previously to the treatment.

Inclusion parameters

The principal patients´ inclusion parameters were the absence of radiographic signs of apical periodontitis with a diagnosis of irreversible pulpitis established by pulp sensitivity testing with heat and cold. The corresponding author performed thermal pulp examination, and a radiographic diagnosis was established by 4 certified endodontists. This study includes only vital teeth in order to avoid false response of the periapical zone due to a periapical pathology or inflammation of the surrounding tissues.

Further clinical requirements for patients´ inclusion were: 1) the purposes and necessities of the study were understood and spontaneously accepted. 2) Patients in adequate physical and mental health were included. It is important the patient´s response to the clinical procedures and not by intermediary subject. 3) Sufficient coronal structure for rubber dam isolation. 4) No previous root canal treatment.

Exclusion parameters

Exclusion parameters were previously root canal treated teeth, gravidity, impossibility to obtain patient's approval, patients who didn't complete inclusion criteria, patients with heart pacemakers, a history of medication for chronic pain or those compromising the immune response, patients younger than 18 years. Non-vital teeth and teeth with apical pathosis, endodontic retreatment, root resorption, undeveloped apex, or a root canal with severe curvature (> 35°) or a radiographically untraceable canal path to the minor foramen were all rejected from this research.

Transportation of the main canal or difficulties during root canal treatment like blocks, ledges, fractures also resulted in the exclusion of patients from the study. The diagnosis of vital pulp was confirmed by the presence of bleeding after gaining access to the pulp chamber. If the thermal test was positive and there was bleeding following pulp exposure, the tooth was established as vital.

Patient selection

One hundred and twenty of 135 patients (93 women and 27 men) aged 18 - 65 years were incorporated in this research while 15 were excluded as not meeting the inclusion criteria (Figure 1 and Table 1). The 120 teeth allocated to each protocol were adequate to confirm an essential sample size. The sample size calculation was done using G*Power version 3.0.10 (Heinrich Heine, Universität Düsseldorf, Düsseldorf, Germany) using the Wilcoxon-Mann-Whitney test. The alpha-type error of 0.05 at a beta power of 0.80 were also stipulated [17]. A total of 80 samples was indicated as the best size required for observing important changes.

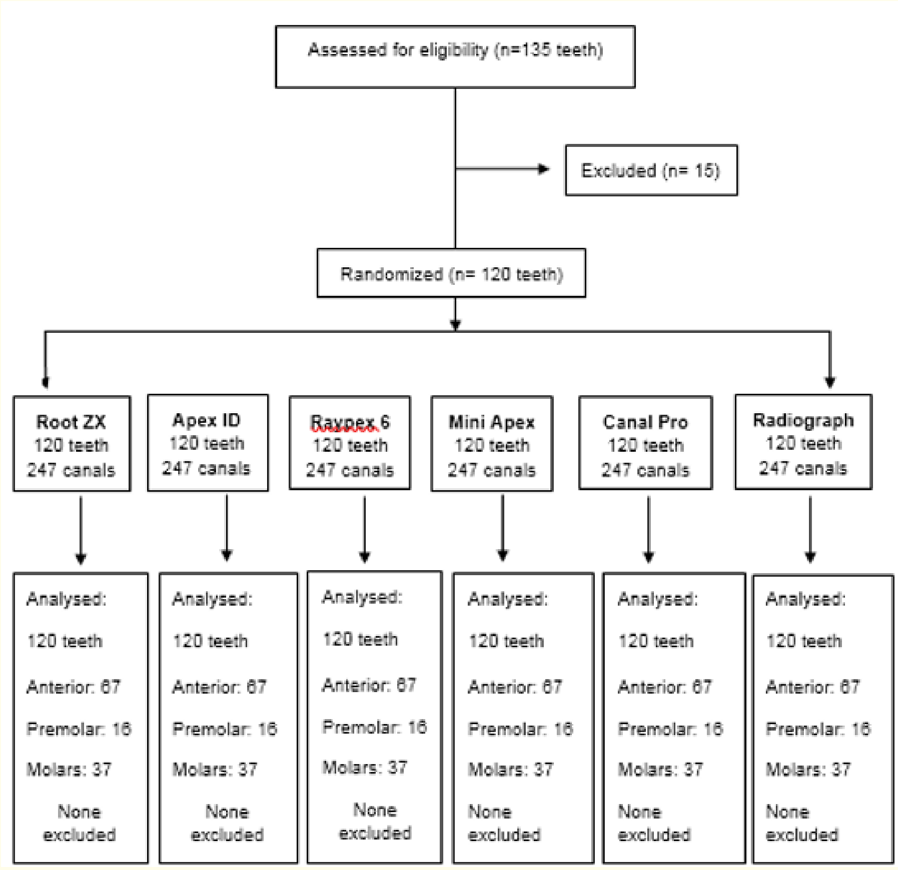

***Figure 1:** CONSORT flowchart for this study.*

	Tooth		No. of canals	
	Maxillary	**Mandibular**	**Maxillary**	**Mandibular**
Central Incisor	39	9	39	9
Lateral Incisor	11	3	11	3
Canine	4	1	4	1
1st Premolar	8	3	16	6
2nd Premolar	4	1	8	2
1st Molar	9	12	36	48
2nd Molar	8	8	32	32
Total	83	37	146	101

Table 1: *Distribution of 120 teeth (247 canals)*

All teeth responded positively to thermal exams and were pulled out for orthodontic, periodontal or prosthodontic purposes. After local anesthesia, rubber dam isolation and access cavity (#331 carbide bur, Dentsply Maillefer USA) the root canals were flared coronally with #1-#2 Orifice Shapers (Dentsply Maillefer USA) using 2.5% NaOCl for irrigation.

Manual K Flex-R files (Moyco, Union Broach) size #10 and #15 were used for the negotiation of the canals, after which the cervical and middle thirds were prepared with ProTaper S1, S2 and F1 instruments (Dentsply Maillefer) placed apically up to 5.0 mm short of the apparent canal length. After preflaring (establishment of a canal path to the minor foramen), the apical constriction was standardized with K Flex-R file size #20 using 2.5% NaOCl as an irrigating solution. The apical constriction of each tooth was identified first with the four EALs and then radiographically.

Treatment Protocol

All the devices electronically and radiographically (Schick Technologies, NY, USA) measured the total sample (N = 120). The EALs were used with the full load. A single qualified endodontist who previously calibrated the EALs performed all the electronic WLs with manual K files calibrated to the required apical limit; the readings were registered after 7 seconds of stability. The order of use of the EALs followed an alternate sequence to permit all of the equipment to be used the same number of periods as the first one.

For the Root ZX: The apical constriction was situated with this EAL according to the company's procedure guidelines [14]. A size #15 K-file was advanced in the canal until the LCD displayed a flashing bar between APEX and 0.5 with corresponding symbol and a flashing tooth with the audible signal indicating that the target had been located.

Two silicone stoppers (to prevent file movement) on the file were placed at the reference point. The instrument was removed from the canal and the length measured to the nearest 0.01 mm with a digital caliper (Mitutoyo America Corporation Aurora IL). This was the insertion length.

For the Apex ID: The apical constriction was detected with the Apex ID EAL per the manufacturer's Instruction Guidelines (©2018 Kerr Corporation, USA). The microprocessor of the unit calculates the change in micro signals to convert the difference into a distance value, which will be displayed on the Apex ID liquid crystal display. The same size #15 k file was used to obtain the insertion length. The Apex ID displays this position graphically and numerically (''0.0''), then the insertion length was measured as above.

For the Raypex 6: This device displays a graphic representation of positions and colors; the activation of the third green light-emitting diode (LED) was considered for describing the effect at position 0.0. Then the insertion length was measured as above.

For the Mini Apex Locator: Electronically interpret the impedance values obtained in the different frequencies during measurements within the canal. (400 Hz and 8 kHz) and determine the WL via an impedance ratio simultaneously.

For the Canal Pro: Canal Pro were used according to the manufacturers' instructions. The lip clip was attached to the patient's lip and a size 15 file was coupled to the electrode of the apex locators. According to the CanalPro (CanalPro™ Apex Locator, user`s guide) apical zone is divided into 11 segments graduated from 1.0 to 0 (Apex) as visual information of file progression. When the apex is reached (read bar at the mark "0" and reading "APEX"), solid tone is emitted. To determine the working length for shaping, it is recommended to subtract 0.5 mm from the apical length.

After completing all the readings with the five EALs, the instruments had their rubber stops adjusted to the occlusal references of the teeth. Then, they were removed and measured in a digital caliper. After the five EALs had established the AC on the same tooth with the same size #15 k file the AC was positioned radiographically by advancing the file until its tip was assumed to be 1.0 mm from the radiographic apex as estimated from the initial radiograph.

A digital radiograph was exposed and if the tip was not 1.0 mm from the radiographic apex the file was repositioned, and an additional radiograph was taken to ensure that it was. The file was removed and after the insertion length was measured it was re-inserted to this length (1 mm from the radiographic apex) and cemented in place with Fuji II LC dual-cure glass ionomer cement (GC Corp, Tokyo, Japan). The file handle was removed with a high-speed bur and after the tooth was extracted without disturbing the file, it was placed in 5.25% NaOCl for 20 minutes to clean the root surface and stored in a 1% Thymol solution.

The tooth was removed from the thymol and with the file in place, the apical 5 mm of the root was ground parallel to the long axis of the canal with a fine diamond bur and abrasive discs. When the file became visible, additional dentine was eliminated while viewing the process under 30X magnification with an OPMI Pico microscope (Carl Zeiss, Munich, Germany) until the instrument tip and the apical AF were in focus. A digital photograph was taken and stored in Adobe Photoshop cc 2017 (Adobe Systems Inc., San Jose, CA, USA).

The distance of the instrument tip from the AC (narrowest part of the canal) was measured and documented as being -1.0 mm or -0.5 mm from the AC; at the AC, or +0.5 mm from the AC. A negative symbol (-) indicated a file short of the AC; A positive symbol (+) indicated it was long of the AC. Since the insertion length was already known, the actual length to the AC was determined by adding or subtracting the distance of the file tip from the AC to the insertion length.

After the actual length (distance from the reference point to the AC) was established the distance of the instrument tip from the AC was calculated for the five EALs by comparing the insertion length with the actual length. The difference was recorded as –1.0 or –0.5 mm, etc. from the AC as shown in tables 2 to 5. The distances of the instrument tip from the AC obtained by the 4 EALs and the distances obtained radiographically were compared using a paired samples t- test and a repeated measure ANOVA evaluation at the 0.05 level of significance.

Results

The percentage of measurements at the AC; 0.5 mm and 1.0 mm short of the AC; 0.5 mm and 1.0 mm through the AC was recorded as shown in tables 2-4.

For anterior teeth, premolars and molars: no measurements were 1.0 mm short of the Apical constriction. For anterior teeth and premolars: No measurements were 0.5 mm short of the Apical constriction (Tables 2-4). In addition, none of the EAL measurements were 1.0 mm through the AC whereas with digital radiographs it was 19.4%, 43.75%, and 35.13% respectively. A WL 1.0 mm through the AC will, in some cases, result in instrumenting and filling beyond the foramen. A WL 0.5 mm short of, or at the radiographic apex, would further increase the likelihood of this happening. There was no statistically significant difference among the five EALs ($p = 0.05$) but it was statically significant between them and digital radiographs (Tables 3-6).

Group	-1 n = 67 (%) Variance Std. Deviation	-0.5 mm n = 67 (%) Variance Std. Deviation	AC n = 67 (%) Variance Std. Deviation	+0.5 mm n = 67 (%) Variance Std. Deviation	+1.0 mm n = 67 (%) Variance Std. Deviation
Root ZX	-	-	59 (88.05%) 0 .099/0.314	8 (11.94%) 0.100/0.340	-
Apex ID	-	-	55 (82.08%) 0 .139/0.373	12 (17.91%) 0.151/0.380	-
Raypex 6	-	-	56 (83.58%) 0.127/0.355	11 (16.41% 0.112/0.350	-
Mini Apex	-	-	57 (85.07%) 0 .098/0.313	8 (11.94%) 0.100/0.340	-
Canal Pro	-	-	54 (80.59%) 0.152/0.389	13 (19.40%) 0.152/0.390	-
Radiograph	-	-	39 (52.20%) 0.609/0.780	38 (56.71%) 0.810/0.94	13 (19.40%) 0.153/0.382

Table 2: *Distance of file tip from the apical constriction determined by Root ZX, Apex ID, Raypex 6, Mini apex, Canal Pro and digital radiograph (67 anterior teeth: 67 canals).*

AC: Apical Constriction.

(+) and (-) values indicate file tip beyond (+) or short (-) of the AC.

p = 0.05.

Distance from AC (mm)	Root ZX n = 16 (% Variance Std. Deviation	Apex ID n = 16 (%) Variance Std. Deviation	Raypex 6 n = 16 (%) Variance Std. Deviation	Mini Apex n = 16 (%) Variance Std. Deviation	Canal Pro n = 16 (%) Variance Std. Deviation	Radiograph n = 16 (%) Variance Std. Deviation
-1	-	-	-	-	-	-
-0.5	-	-	-	-	-	-
AC	15 (93.75%)	14 (87.50%)	15 (93.75%)	15 (93.75%)	14 (87.50%)	6 (37.5%)
	0.194/0.440	0.189/0.457	0.194/0.44	0.194/0.440	0.189/0.457	0.08/0.195
0.5	1 (6.25%)	2 (12.5%)	1 (6.25%)	1 (6.25%)	2 (12.5%)	10 (62.5%)
	0.016/0.029	0.02/0.065	0.016/0.029	0.016/0.029	0.02/0.065	0.13/0.325
+1.0	-	-	-	-	-	7 (43.75%) 0.09/0.227

Table 3: *Distance of file tip from the apical constriction determined by Root ZX, Apex ID, Raypex 6, Canal Pro and Radiograph (16 premolars: 32 canals).*

AC: Apical Constriction.

(+) and (-) values indicate file tip beyond (+) or short (-) of the AC.

p = 0.05.

Distance from AC (mm)	Root ZX n = 37	Apex ID n = 37	Raypex 6 n = 37	Mini Apex n = 37	Canal Pro n = 37	Radiograph n = 37
-1	-	-	-	-	-	-
-0.5	-	-	-	-	-	-
AC	31 (83.78%)	30 (81.08%)	31 (83.78%)	30 (81.08%)	29 (78.37%)	8 (21.62%)
0.5	6 (16.21%)	7 (18.91%)	6 (16.21%)	7 (18.91%)	8 (21.62%)	14 (37.83%)
+1.0						13 (35.13%)

Table 4: *Distance of file tip from the apical constriction determined by Root ZX, Apex ID, Raypex 6, Canal Pro and Radiograph (37 molars: 148 canals).*

AC: Apical Constriction.

(+) and (-) values indicate file tip beyond (+) or short (-) of the AC.

p = 0.05.

Anteriors	RZX: 88.05%	AID: 82.1%	RAY 6: 83.6%	MINI: 85.07%	CP: 80.6%	Rx: 52.20%
Premolars	RZX: 93.75%	AID: 87.5%	RAY 6: 93.7%	MINI: 93.75%	CP: 87.5%	Rx: 37.5%
Molars	RZX: 83.78%	AID: 81.08%	RAY 6: 83.78%	MINI: 81.08%	CP: 78.37%	Rx: 21.62%

Table 5*: Percentage of measurements at the AC with the four EALS.*

Root ZX= (RZX); Apex ID= (AID); Raypex 6= (RAY 6) Canal Pro= (CP); Mini Apex= (MINI) and Radiograph= (Rx).

Anteriors	RZX: 11.94%	AID: 17.91%	RAY 6: 16.41%	MINI: 11.94	CP: 19.40%	R: 56.71%
Premolars	RZX: 6.25%	AID: 12.5%	RAY 6: 6.25%	MINI: 6.25	CP: 12.5%	R: 62.5%
Molars	RZX: 16.21%	AID: 18.91%	RAY 6: 16.21%	MINI: 18.91	CP: 21.62%	R: 37.83%

Table 6: *Percentage of measurements at 0.5mm through the AC with the four EALS.*

Root ZX= (RZX); Apex ID= (AID); Raypex 6= (RAY 6) Canal Pro= (CP); Mini Apex= (MINI) and Radiograph= (Rx)

Discussion

The goal of this research was to assess *in vivo* the precision of five EALs: RootZX, Apex ID, Raypex 6, Mini Apex Locator and Canal Pro for establish working length as related to digital radiographs at levels 1 mm short of the apical foramen (-1.0), followed by measurements at (-0.5), (0.0), (+ 0.5) and (+1.0).

Digital images and EALs were investigated solely or in comparison to each other. However, neither *in vitro* nor i*n vivo* results can be a true representative of clinical situations in which the whole treatment is done in the mouth [14]. On the other hand, randomized clinical studies may provide high-level of evidence for clinical practice since they reflect a truly clinical condition. In the present study, only teeth that were being extracted from adult patients for periodontal, prosthetic or orthodontic reasons were used.

All measurements were conducted by the same experienced and trained operator, thus eliminating the possibility of operator bias. A WL is gained radiographically by setting the tip of an instrument a certain distance, commonly 1.0 mm, from the radiographic apex. This method lacks accuracy because the 1.0 mm is measured from the end of the root (radiographic apex) rather than the apical foramen. Wrbas., *et al*. [25] urged caution to avoid overestimating WL because the AF frequently was not at the apex. Gutiérrez and Aguayo [8], recorded a wide variability in distances between the foramen and radiographic apex ranging from 0.20 to 3.40 mm.

There is a common agreement in the endodontic community that WL should be situated at the AC Kuttler [1], found that the AC averaged 0.5 to 0.75 mm from the AF and that the distance increased with age because of cementum deposition. Chapman [26] and Dummer., *et al.* [3] found that the AC was located 0.5 - 1.0 mm from the apex in 92% and 95% of the inspected teeth, separately. Hassanien., *et al.* [27] detected the AC an average distance of 1.2 mm from the AF. In light of these studies, it would seem that there is plenty of justification to establish a WL 1.0 mm short of the radiographic apex.

Unfortunately, this statement is not always accurate in locating the AC and care should be used because a WL 1 mm short of the radiographic apex and supposed to be close to the AC may actually be beyond the AF. When this occurs, an instrument passing through a necrotic pulp and through the foramen will most likely carry microorganisms and its products into the apical area [28,29]. Receiving an indication from an EAL when the AC is located would be very beneficial in preventing this mishap.

The use of an EAL to calculate WL has extended acceptance. Even though the user must be alert of the possible sources of miscalculation (metallic restorations, salivary contamination, dehydration, etc.), the present study and other scientific papers have presented that the precision of EALs is better than radiographs [7,30,31]. An *in vivo* study [32] the Root ZX was within 0.5 mm of AC 96% of the time, a value similar to our study (100%). In general, our study also agrees with others [33] that EALs are more accurate than radiographs and greatly reduce the chance of instrumenting and filling short of or beyond the apical foramen (Tables 3-6).

Being 1.0 mm through the AC increases the risk of over instrumentation and filling. In this study, using a radiographically determined WL 1.0 mm from the radiographic apex resulted in 19.4% of the anterior teeth, 43.75% of the premolars, and 35.13% of the molars being 1.0 mm through the AC. In comparison, no EALs measurements for anterior, premolar and molar teeth were 1.0 mm through the AC. Thus, the null hypothesis was accepted.

The limitations and disadvantages of using only the radiographic method to determine WL are well known. Superimposition of anatomic structures could contribute to increasing a clinician's inaccuracy in locating WL. Additionally, prior to digital radiography, radiation was an even greater concern. However, since the joint use of radiographs together with EAL results in greater accuracy [34], radiographic verification of WL length is still desirable [35,36]. These data are interesting because clinicians who join the radiographs and EALs results for performing root canal measurements occasionally find that the outcomes do not coincide. In our opinion, in the happening of disagreement among the two measurement approaches, preference should go to the electronically determined value.

So, it can be said that the accurate determination of WL will be dependent on the ability of the clinician to read radiographs, an excellent monitor to see and interpret digital radiographs, correct assumption of apical constriction with the help of an EAL, handling and using a combination of all methods, application of logic, knowledge of anatomy of the canals and especially the apical third and tactile sense.

The results of this study do not suggest that the EALs replace radiographs. However, they are the ideal tools for complementing radiographic methods of WL determination and thus can help in reducing the number of radiographs taken in this regard. Electronic root canal measurement is an objective and acceptably reproducible technique.

Conclusion

Under clinical conditions, EALs identified the AC with greater accuracy and predictability than digital radiographs. No significant difference was apparent comparing the accuracy of the five EALS. All achieved a clinically acceptable determination of WL and were significantly more accurate than radiographs.

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Conflict of Interest

The authors deny any conflicts of interest related to this study.

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