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Research Article

Comparison of Working Length Determination in Teeth with Vital Pulps with Digital Radiographs and Four Electronic Apex Locators. An *In Vivo* Study

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Abstract

Introduction: The aim of this study was to evaluate *in vivo* the accuracy and predictability of four EALs for determining working length as compared to radiographs: RootZX, Apex ID, Joypex 5 and Propex Pixi.

Methods: One hundred and twenty patients (247 canals) contributed in the study. The measurements obtained by the four EALs and radiographs relative to the actual location of the AC were compared using a paired samples t test, X^2 test.

Results: For anterior teeth, EALs and radiographs located the minor foramen 87%, 75%, 75%, 87% and 62% of the time, respectively. For premolar teeth, EALs and radiographs located the minor foramen 92.85%, 85.71%, 78.57%, 85.71% and 57.14% of the time, respectively. For molar teeth, the Root ZX, EALs and radiographs located the minor foramen 90%, 85%, 80%, 85% and 70% 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.

Conclusion: Under clinical conditions the EALs identified the apical constriction (minor foramen) with high degree of accuracy. EAL were more accurate, compared to radiographs with the potential to greatly reduce the risk of instrumenting and filling beyond the apical foramen.

Keywords: Apical foramen, Constriction, Root apex, Root ZX, Mini apex, Joypex

Introduction

The success of root canal treatment has to be done on the correct implementation of all stages of the procedure from diagnosis to the canal filling. Among these steps, the determination of working length (WL) is a challenge and depends on the anatomy of the root end. Filling root canals should not extend beyond the tooth apex. The apical constriction (AC), is a reasonable site for working length since it frequently corresponds with the constricted width of the canal [1,2]. Dummer PHM, et al. [3] recognized that it is hard to locate the AC *in vivo* with reliance because of its location.

The cementodentinal junction has been recommended as the histological site for working length because it represents the shift among two tissues [4]. The situation of this point is commonly recognized as being 0.50 mm to 0.75 mm cervical to the apical foramen [5] but, as with the AC, the precise position of the cementodentinal junction is hard to find *in vivo*. Frequently, this point is considered to be co-located with the minor foramen [6]; nonetheless, this is not all the time the case [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 understanding and conception. Even when a radiographic technique is recommended modifications of images has been found to be around 5% [7].

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

The use of electronic apex locators (EALs) to determine the WL has become common [9]. Periapical radiographs have been considered as the traditional and most appropriate way of gaining suggestion on the configuration of the root canal and its adjacent tissues [10-13]. Digital radiography still has limitations including image distortion, superposition of roots and adjacent anatomical structures, and higher radiation exposure compared to electronic methods [9].

Periapical radiographs are still an aid for diagnosis, for working films (e.g. calculating the working length of root canals, fitting gutta percha cones), to confirm the final fill, and for follow-up comparisons at recall examinations. The mechanism of EALs based on the principle of frequency dependent impedance, EALs have been trusted with the basic role in determining the WL. Though, even operating the same principle, modern EALs operate mechanisms that vary from the initially planned ones.

Several use the impedance quotient principle such as Root ZX (0.4 and 8 kHz) (J. Morita, Tokyo, Japan) [14,15]and Apex ID (0.5 and 5 kHz) (SybronEndo, Orange, CA) [16,17]. Joypex 5, Denjoy Dental Corporation, Changsha City, China and Propex Pixi (Dentsply Sirona, Maillefer Instruments Holding Sàrl Chemin du Verger 3 CH-1338 Ballaigues Switzerland) [18,19] use the square root of impedances in 2 frequencies.

EALs have the potential to enable the identification of the device inside the canal, allowing more precise *in vivo* determination of working length (WL) [20]. Recent EALs have a great consistency and high accuracy and in finding the major AF regardless of the internal environment [21].

EALs have the ability to reduce the number of radiographs used through root canal therapy [22]. Modern EALs can locate the AF and the AC with extraordinary precision. The accuracy of measurement might also differ on the file size and the anatomy of the root canal and apical foramen.

Considering the value of the precise determination of WL in the success of endodontic therapy [23], the aim of this study is to evaluate *in vivo* the accuracy and predictability of four modern and precise EALs: Root ZX, Apex ID, Joypex 5 and Propex Pixi for determining WL as compared to digital radiographs. The null hypothesis considered was that no significant differences would be found between the EALs.

Materials and Methods

G*Power version 3.0.10 (Heinrich Heine, Universität Düsseldorf, Düsseldorf, Germany) were used to calculate sample size by using the Wilcoxon-Mann-Whitney test [17]. A total of 42 samples were indicated as the best size required for observing important changes.

This clinical study was achieved at the Autonomous University of Baja California, School of Dentistry, Tijuana, Mexico. The study protocol was accepted by the Ethics Committee (71/2018) 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 treatment.

The 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 the radiographic diagnosis was established by 2 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) Sufficient coronal structure for rubber dam isolation. 3) No previous root canal treatment.

Exclusion parameters were previously root canal treated teeth, gravidity, impossibility to obtain patient's approval, patients who didn't complete inclusion criteria, 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.

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

Forty-two of 54 patients (31 women and 11 men) aged 18-55 years were incorporated in this study while 15 were excluded as not meeting the inclusion criteria. The 42 teeth (116 canals) allocated to each protocol were adequate to confirm an essential sample size. All teeth responded positively to thermal exams and were extracted for periodontal or prosthodontic purposes.

All clinical procedures and measurements were performed by a single experienced operator. After local anesthesia, rubber dam isolation and access cavity (#331 carbide bur, Dentsply Maillefer USA) and refined with an Endo Z bur (Dentsply Maillefer). The root canals were flared cervically 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 SX, S1 and S2 instruments (Dentsply Maillefer) inserted 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 EALs electronically and radiographically (Schick Technologies, NY, USA) measured the total sample (N = 42). The EALs were used with a 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. Measurements were considered to be valid if the reading remained stable for at least 5 seconds. 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 AC 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 AC 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 AC was detected with the Apex ID per the manufacturer's Instruction Guidelines (©2018 Kerr Corporation, USA). The same size #15 file used for the Root ZX. The Apex ID displays this position graphically and numerically (''0.0''), then the insertion length was measured as above. For the Joypex 5 until the device reach the "0.0" level, according to the manufacturer's recommendations. Then the insertion length was measured as above.

For the Propex Pixi. The Propex Pixi has a LED that represents the AC position (0.0), then the insertion length was measured as described in the previous protocol.

After completing all the readings with the EALs, the instruments had their rubber stops adjusted to the occlusal references of the teeth. The teeth were extracted and the roots were analyzed with an operating microscope for the presence of fractures or any other type of change that would exclude the tooth.

After the four EAL had established the AC on the same tooth with the same size #15 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 min 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 four EAL 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 1-4. 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.

Table 1: Distribution of 42 teeth (116 canals).

	Tooth		No. of Canals	
	Maxillary	Mandibular	Maxillary	Mandibular
Central Incisor	4	0	4	0
Lateral Incisor	3	0	3	0
Canine	1	0	1	0
1st Premolar	4	2	8	4
2nd Premolar	5	3	10	6
1st Molar	5	7	20	28
2nd Molar	4	4	16	16
Total	26	16	62	54

Table 2: Distance of file tip from the apical constriction determined by Root ZX, Apex ID, Joypex 5, Propex Pixi and Radiograph (8 anterior teeth: 8 canals).

Group	1.0 m n=8 (%) Variance Std. Deviation	-0.5 mm n=8 (%) Variance Std. Deviation	AC n=8 (%) Variance Std. Deviation	+0.5 mm n=8 (%) Variance Std. Deviation	+1.0 mm n=8 (%) Variance Std. Deviation
Root ZX	-	-	7 (87.5%)	1 (12.5%)	-
			0 .099/0.314	0.100/0.340	
Apex ID	-	-	6 (75%)	2 (25%)	-
			0.139/0.373	0.151/0.380	

Joypex 5	-	-	6 (75%)	2 (25%)	-
			0.139/0.373	0.151/0.380	
Propex Pixi	-	-	7 (87.5%)	1 (12.5%)	-
			0.099/0.314	0.100/0.340	
Radiograph	-	-	5 (62.5%)	1 (12.5%)	2 (25%)
			0.115/0.373	0.810/0.94	0.153/0.382

AC: Apical Constriction (+) and (-) values indicate file tip beyond (+) or short (-) of the AC. p= 0.05

Table 3: Distance of file tip from the apical constriction determined by Root ZX, Apex ID, Joypex 5, Propex Pixi and Radiograph (14 premolars: 28 canals).

Distance from AC (mm)	Root ZX n = 14 (%)	Apex ID n = 14 (%)	Joypex 5 n= 14 (%)	Propex Pixi n= 14 (%)	Radiograph
-1.0	-	-	-	-	-
-0.5	-	-	-	-	-
AC	13 (92.85%)	12 (85.71%)	11 (78.57%)	12 (85.71%)	8 (57.14%)
+0.5	1 (7.14%)	2 (14.28%)	3 (21.42%)	2 (14.28%)	5 (35.71%)
+1.0					1 (7.14%)

AC: Apical Constriction (+) and (-) values indicate file tip beyond (+) or short (-) of the AC. p= 0.05

Table 4: Distance of file tip from the apical constriction determined by Root ZX, Apex ID, Joypex 5, Propex Pixi and Radiograph (20 molars: 80 canals).

Distance from AC (mm)	Root ZX n=20	Apex ID n=20	Joypex 5 n=20	Propex Pixi n= 20	Radiograph n=20
-1.0	-	-	-	-	-
-0.5	-	-	-	-	-
AC	18(90%)	17 (85%)	16 (80%)	17 (85%)	14 (70%)
0.5	2 (10%)	3 (15%)	4 (20%)	3 (15%)	5 (25%)
1					1 (5%)

AC: Apical Constriction (+) and (-) values indicate file tip beyond (+) or short (-) of the AC. p = 0.05

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 anteriors, premolars, and molars: no measurements were 1.0 mm short of the Apical constriction. For anteriors 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 25% in anterior teeth, 7.14% in bicuspids and 5% in molars 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. For anterior teeth, EALs and radiographs located the minor foramen 87%, 75%, 75%, 87% and 62% of the time, respectively. For premolar teeth, EALs and radiographs located the minor foramen 92.85%, 85.71%, 78.57%, 85.71% and 57.14% of the time, respectively. For molar teeth, the Root ZX, EALs and radiographs located the minor foramen 90%, 85%, 80%, 85% and 70% of the time, respectively. There was no statistically significant difference among the four EALS (p= 0.05) but it was statically significant between them and digital radiographs.

Discussion

The goal of this study was to evaluate *in vivo* the accuracy and predictability of four EALs: Root ZX, Apex ID, Joypex 5 and Propex Pixi for determining WL as compared to digital radiographs. Usually, radiographs have been the primary means for determining WL. However, they have inherent restrictions, being two-dimensional images of three-D objects.

Both methods were used to investigate conventional radiographs, digital images and EALs solely or in comparison to each other. However, neither *in vitro* nor *in 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.

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 1.0mm, from the radiographic apex. This method lacks accuracy because the 1.0mm is measured from the end of the root (radiographic apex) rather than the apical foramen. Wrbas KT, et al. [25] urged caution to avoid overestimating WL because the AF frequently was not at the apex. Gutiérrez & Aguayo [8] recorded a wide variability in distances between the foramen and radiographic apex ranging from 0.20 to 3.40mm.

There is a common agreement in the endodontic community that WL should be situated at the AC. Kuttler Y [1], found that the apical constriction averaged 0.5 to 0.75 mm from the AF and that the distance increased with age because of cementum deposition. Chapman C [26] and Dummer PMH, et al. [3] found that the AC was located 0.5 -1.0mm from the apex in 92% and 95% of the inspected teeth, separately. Hassanien EE, et al. [27] detected the apical

constriction an average distance of 1.2mm from the AF. In light of these studies, it would seem that there is a plenty justification to establish a WL 1.0 mm short of the radiographic apex.

Unfortunately, this statement is not always accurate in locating the apical constriction and care should be used because a WL 1 mm short of the radiographic apex and supposed to be close to the apical constriction 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 apical constriction 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 [7,30-32]. 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.

Being 1.0 mm through the apical constriction 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 apical constriction. 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].

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.

Conclusion

Thus, based on the results of this study it can be concluded that EALs identified the AC with greater accuracy and predictability than digital radiographs. All achieved a clinically acceptable determination of WL and were significantly more accurate than radiographs.

Acknowledgment

None.

Conflict of Interest

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

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