Original Article

Effect of Different Electroconductive Root Canal Irrigations on the Accuracy of Different Apex Locators: An *In Vitro* Comparative Study

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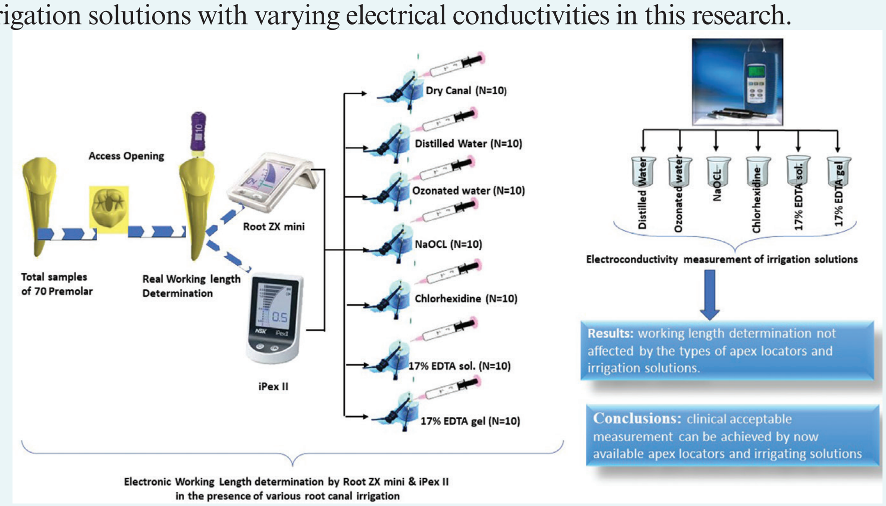
Abstract

Aim: An accurate working length (WL) estimation is fundamental to a successful endodontic therapy. The objective of this comparative *in vitro* research was to investigate the performance of iPex II and the Root ZX Mini electronic apex locators (EALs) in measuring root canal WL with different irrigant solutions and their relation to the electrical conductivity of irrigation solutions. **Materials and Methods:** Seventy sound permanent lower premolar teeth, each with a single root and developed apices, were used. Under an X15 stereomicroscope, the real working length was determined with the aid of a #10 file. After that, teeth were placed into an alginate model, and the iPex II and Root ZX Mini were used for the detection of electronic working length with various irrigants. Seventy teeth were randomly distributed into seven groups, 10 per each group (group I: dry canal; group II: distilled water; group III: ozonated water; group IV: 5% sodium hypochlorite (NaOCl); group V: 2% chlorhexidine, group VI: 17% ethylenediaminetetraacetic acid (EDTA) solution, and group VII: 17% EDTA gel). The difference in WL was calculated by deducting real working length from its electronic working length. The study also evaluates the electrical conductivity of the seven endodontic irrigant solutions. The two-way analysis of variance (ANOVA) test was used for statistical analysis. **Results:** Statistically, neither both types of EALs (P = 0.088) nor various irrigating solutions with varying electrical conductivities (P = 0.099) significantly affect the accuracy of EL estimation. **Conclusions:** There were no significant differences between the accuracy of the Root ZX Mini and the iPex II. The accuracy of both apex locators is unaffected in the presence of various irrigation solutions with varying electrical conductivities in this research.

Graphical Abstract



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Introduction

Any endodontic procedure needs a precise working length (WL) estimation to be successful. The WL of a root canal is "the distance between a coronal reference point and the preferred end point for cleaning and obturation."[1] Controversial issues have been observed between those who consider the occurrence of any filling materials outside the root canal to be significant irritations and those who consider it an indicator of patency to the apical aperture.[2]

Cleaning and reshaping in endodontics eliminate bacteria, bacteria by-products, and debris from root canals following irreversible pulp diseases, thereby preventing further infection and inflammation of the periapical area.[3]

The minor apical aperture, or cemento-dential junction, is the optimal location for reshaping and filling root canals. The periodontal ligament begins here and the pulp terminates here. When endodontic procedures are performed at this point, the periapical tissues, which have the ability to regenerate, and produce an obstacle that protects the periodontium, are conserved.[4] The termination of root canal chemomechanical preparation and obturation at the apex is disputed because of their morphological diversity.[5]

Radiography is the most widespread and commonly utilized method for assessing WL. However, it might be confusing in situations of resorption and apical constriction.[6] Historically, the method of WL estimation done by subtracting 0.5–1 mm from the distance measured between the radiographic apex and the crown has also been reported to be incorrect and imprecise due to radiographic image distortion.[7]

The implementation of electronic apex locators (EALs) has contributed to the reliability of WL estimation, leading to increased precision in the results in comparison to the radiographic method.[8] These apex locators (ALs) are useful, especially when the apical portion of the canal is covered by some anatomical structure that cannot be detected by using conventional radiography. In addition to that, one of the main benefits of EALs is that it reduces the number of times a patient is exposed to ionizing radiation and also decreases the treatment duration.[3] Their mechanism of action relies on the difference in tissue conductivities between inside and outside of the canal at the apex.[9] Since then, EALs have emerged as valuable tools in modern endodontics.[10]

There have been many distinct EAL models established over the past few years, and while they all implement the same basic idea, they do so in a somewhat distinct manner.[5] EALs with dual and multifrequency technology are used to detect the apical foramen in different canal circumstances. Modern ALs are 82%–96% accurate within 0.5 mm.[11]

Irrigation is the current gold standard for removing chips of dentine and tissues during instrumentation.[12] Historically, there have been many different irrigation materials used, but the most widely used and effective materials for root canal irrigation were sodium hypochlorite (NaOCl), chlorhexidine (CHX), and ethylenediaminetetraacetic acid (EDTA).[13]

Ozonated water destroys bacteria, fungi, viruses, and protozoa. Ozone is being considered an endodontic antiseptic because of its antibacterial properties.[14] The potential impact of irrigation solutions on the precision of EALs has attracted a lot of attention.[13]

Root ZX Mini (Morita, Kyoto, Japan) is a third-generation AL that measures impedance at 8 and 0.4 kHz.[15] iPex II (NSK, Tochigi, Japan) is a fourth-generation AL advertised for measuring both capacitance and resistance.[16]

The main goal of this comparative *in vitro* research was to assess the accuracy of WL estimation by using the iPex II and Root ZX Mini. The null hypotheses tested in the research were that neither types of EALs nor different types of irrigating solutions affect the accuracy of WL estimation.

Materials and Methods

The Research Ethics Committee at the University of Mosul's College of Dentistry approved this study (approval code: UoM.Dent/DM.H.L. 56/21). The sample size was estimated by using G*Power program, version 3.1.9.7. The sample size was determined based on the previous studies,[17-19] with the effect of size set to

0.8, α error prob set to 0.05, and power ($1-\beta$ err prob) set to 0.95. The sample size was 10, and the actual power was 0.9. This study utilized seventy single-rooted, permanent lower premolar teeth that were extracted for periodontic, prosthodontic, or orthodontic reasons from patients aged 25–35 years. Based on the buccolingual and mesiodistal digital radiograph, the selected teeth meet the following criteria: completely developed apices and single straight canals (<10° of curvature according to Schneider's technique[20]). The exclusion criteria for the teeth would be any of the following: presence of any coronal fillings, any previous pulp or root canal therapy or internal resorption, or canal calcification.

Using an X15 stereomicroscope (Zeiss Stemi, CarlZeiss, Germany), the teeth were examined for any possible cracks or fracture lines or any sign of root resorption.

All teeth were kept in a 1% thymol solution. The removal of tissue remnants on the root was accomplished with the use of a scaler. Diamond burs were used for preparing the access to cavities, while the apical patency was assessed using the #8 K-file.

Using an X15 stereomicroscope (Zeiss Stemi, Carl Zeiss), the real working length (RWL) was obtained by introducing a #10 file into the canal till the file's tip was barely evident at the apical aperture. At this point, the distance between the file's tip to the stopper that has been set to the coronal reference point is calculated by using a digital caliper (INSIZE, Mumbai, India). All teeth were standardized to have a uniform WL of 20 mm, ensuring a constant and dependable coronal reference point. Teeth exceeding this length will be modified using a diamond disk. Conversely, any teeth shorter than this specified length would be removed from the study.

Alginate (Lascod Kromopan, Florence, Italy) that had been freshly mixed was poured into a plastic tube. Within these tubes, lip clip of EALs and teeth were put into an alginate model. The clips were then maintained in place until the alginate had completely set, thus replicating the oral situation. The model was immediately used for the purpose of humidity maintenance.[21]

Flexofile #10 was introduced into the root canal till the AL signal indicated the position at the "0" mark. A rubber stopper was then placed to secure the file in position. After the device's screen indicators remained stable for a duration of 5 s, the reading was approved and the file was removed. The distance between the fil's tip to the rubber stopper was calculated using a digital caliper. The electronic working length (EWL) was estimated by a single endodontist, who repeated the technique five times. The average value of these five readings was documented as the EWL. The aforementioned technique was utilized with both EALs during irrigation with various irrigants.

Seventy teeth were randomly distributed into seven groups, 10 per each group: Group 1 (control): both types of EALs were used to measure EWL in dried canals in this group; group 2: distilled water; group 3: ozonated water (ozone generator, OZX300AT, Enaly, Shanghai, China); group 4: 5% NaOCl (Microvem, Istanbul, Turkey); group 5: 2% CHX (Consepsis®, Ultradent, South Jordan, UT, USA); group 6: 17% EDTA (PULPDENT, Watertown, USA); and group 7: EDTA gel at 24% (Biodinamica, Ibiporã, Brazil).

The irrigation solutions were used to fill all the teeth up to the coronal orifice. Any excess solution was removed using cotton pellets. The WL of the canal was afterward assessed using EALs. Following the completion of the readings, a thorough irrigation procedure was conducted on all teeth using 5 mL of distilled water. This irrigation was performed with a 30-G double-sided port needle, and subsequent drying with paper points was carried out to ensure the removal of any residual leftovers from the previous irrigation.

To calculate the difference in WL for each tooth, subtract the RWL from the EWL. The positive value showed that the apical foramen had been exceeded, and the negative value showed a shorter response than the recorded value, whereas the measurement within 0.5 mm considered an acceptable range of the real length.

The electrical conductivity of the irrigating solutions utilized in the study was measured using a SensoDirect 150 electrical conductivity tester (Tintometer Inc., Sarasota, FL, USA). The experiment involved filling glass beakers halfway with 50 mL of an irrigant. The electrode of the taster was then dipped in the beakers at a temperature of 25°C. After each measurement, the electrode was thoroughly washed with deionized water and subsequently calibrated before its second usage using a different solution. Five repetitions were conducted for each irrigant, and the resulting measurements were averaged.

Using the SPSS (version 21, IBM, SPSS Statistic, USA) program, the results were analyzed using the two-way analysis of variance (ANOVA) test.

Results

The raw data of the study and the descriptive statistics for the results of WL accuracy of both types of

Table 1: Raw data of the study

iPex II							Root ZX Mini						
Dry canal	Distilled water	Ozonated water	5% NaOCl	2% CHX	17% EDTA	17% EDTA gel	Dry canal	Distilled water	Ozonated water	5% NaOCl	2% CHX	17% EDTA	17% EDTA gel
0.0	0.0	0.0	0.0	0.0	−0.1	0.0	0.0	0.0	0.0	0.0	0.0	−0.1	0.0
0.0	0.0	0.0	0.0	0.0	−0.2	−0.1	0.0	0.0	0.0	0.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	−0.1
0.0	0.0	0.0	0.1	0.0	0.0	−0.1	0.1	0.0	0.0	−0.1	0.0	−0.1	0.0
0.1	−0.2	−0.1	0.1	0.0	0.0	0.0	0.0	0.1	−0.1	0.0	0.1	0.1	0.0
−0.1	0.0	0.0	0.1	0.0	0.0	0.0	−0.1	0.0	0.0	0.0	0.0	0.0	−0.1
0.0	0.0	0.0	−0.1	0.0	−0.1	−0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
−0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	−0.1	0.0

EDTA = ethylenediaminetetraacetic acid, NaOCl = sodium hypochlorite

Table 2: Descriptive statistics for the results of the study for both types of EALs with various root canal irrigants

Device	Irrigants	Mean	Standard deviation	N
iPex II	Dry (control)	−0.050	0.1650	10
	Distilled water	0.010	0.0738	10
	Ozonated water	0.000	0.0471	10
	5% NaOCl	0.020	0.0632	10
	2% CHX	0.000	0.0000	10
	17% EDTA solution	−0.050	0.0707	10
	17% EDTA gel	−0.040	0.0516	10
Root ZX Mini	Dry (control)	0.000	0.0471	10
	Distilled water	0.010	0.0738	10
	Ozonated water	0.000	0.0471	10
	2% CHX	0.020	0.0422	10
	5% NaOCl	0.040	0.1647	10
	17% EDTA solution	−0.020	0.0632	10
	17% EDTA gel	−0.020	0.0422	10

EDTA = ethylenediaminetetraacetic acid, NaOCl = sodium hypochlorite

EALs with various root canal irrigation solutions are presented in Tables 1 and 2, respectively.

The two-way ANOVA test revealed that significant differences were not present between the two types of EALs (P = 0.088). There was also no significant difference between various types of root canal irrigation solutions (P = 0.099). In addition, the results indicated no interaction between the two devices and various root canal irrigants (P = 0.982) [Table 3].

Table 3: Results of two-way ANOVA

Sources	Types III sums of Squares	df	Mean square	F	Significance
Intercept	0.007	1	0.007[a]	1.154	0.285
Device	0.018	1	0.018	1.154	0.088
Irrigant	0.068	6	0.011	1.827	0.099
Device × irrigant	0.007	6	0.001	0.181	0.982
Error	0.780	126	0.006		
Total	0.880	140			
Corrected Total	0.873	139			

ANOVA = analysis of variance

[a] R^2 = 0.106 (adjusted R^2 = 0.014)

All the WL occur within a reasonable range of ±0.5 mm. The RWL coincides with the EWL in 75% of dry canals, 85% of canals with distilled water, 80% of canals with ozonated water, 70% of canals with NaOCl, 90% of canals with CHX, 65% of canals with EDTA solution, and 60% of canals with EDTA gel [Table 4].

With regard to the electrical conductivity of various irrigating solutions utilized in this study, the electrical conductivity of NaOCl and EDTA (gel and solution) was higher than that of CHX, distilled water, and ozonated water, respectively [Table 5].

Discussion

The determination of an accurate WL is of extreme value in root canal therapy, since substantial evidence indicates that instrumentation that extends beyond or stops short of the apex might have a negative impact on the treatment's outcome.[22] In the early versions

Table 4: Position and percentage of the file tip in relation to the RWL with various irrigant solutions

Distance from apical foramen (mm)	Dry	Distilled water	Ozonated water	NaOCl	CHX	EDTA solution	EDTA gel
−0.1 to −0.5	3 (15%)	2 (10%)	2 (10%)	2 (10%)	0(0%)	7 (35%)	7 (35%)
0.0	15 (75%)	17 (85%)	16(80%)	14 (70%)	18 (90%)	13 (65%)	12 (60%)
0.1 to o.5	2 (10%)	1 (5%)	2 (10%)	4 (20%)	2 (10%)	0 (0%)	1 (5%)

EDTA = ethylenediaminetetraacetic acid, NaOCl = sodium hypochlorite

Table 5: Electrical conductivities (expressed in µS/cm) of six different irrigants

Irrigants	Electrical conductivities (µS/cm)
Distilled water	2 ± 0.11
Ozonated water	1.2 ± 0.25
5% NaOCl	135.5 ± 1.2
2% CHX	2.16 ± 1.2
17% EDTA solution	20.3 ± 0.94
17% EDTA gel	15.32 ± 0.28

EDTA = ethylenediaminetetraacetic acid, NaOCl = sodium hypochlorite

of EALs, the accuracy of WL measurements may be compromised in part to the existence of conductive fluids within the canal. Nevertheless, manufacturers assert that the most recent versions of EALs are designed to be impervious to the effects of irrigation solutions.[23] Numerous investigations have been conducted to calculate the precision of EALs through both *in vitro* and *in vivo* experiments. These investigations have showed varying levels of precision and reliability in the measurement of WL when different irrigant types and electroconductive properties are present.[24,25]

In newer generations of EALs, multiple frequencies are used to determine WL, resulting in a more precise WL measurement in the presence of different electrolytes. However, the presence of highly electroconductive irrigants, such as saline, local anesthetic solution, CHX, blood, hydrogen peroxide, EDTA, irrigating fluids, and NaOCl, may compromise the accuracy of the EAL's performance.[26]

Different irrigation solutions have been utilized in endodontics owing to their antibacterial, lubricating, and dissolving capacities. However, the presence of these irrigations may interfere with the use of EALs and reduce the precision of measurements. Numerous studies have indicated that WL can be measured in the presence of various electroconductive fluids; however, the accuracy of the EAL may be affected by the irrigant solution used.[27–29]

In this *in vivo* research, alginate was used as a mold to hold the teeth in position and to simulate human periodontium in the oral cavity. Moreover, set alginate's consistency stops fluid from entering the canal, which can cause inaccurate electronic reading, the ease of manipulation, reasonable cost, and excellent electroconductive properties validated the use of alginate in a similar study.[30]

In this study, significant difference was not present between the accuracy of both EAL types ($P = 0.088$). Both the iPex II and Root ZX Mini were able to accurately reproduce WL in dry canals. This result is consistent with the findings of Kang and Kim,[31] who studied the accuracy of seven types of EALs using different irrigant solutions and discovered that the accuracy of EALs was not affected by the dry condition. However, the accuracy may be improved in dry canals, which may have less electrical conductivity near the apical region than wet canals, which may have more electrical conductivity and negatively affect WL estimation. In accordance with previous studies,[32,33] Root ZX measurements in dry canals were not consistent.

This study utilized various irrigant solutions, including NaOCl, CHX, ozonated water, EDTA (gel and solution), and distilled water. The findings showed that the use of NaOCl resulted in less accurate results in determining WL compared to CHX. However, there was no statistically significant difference for both EALs when used with NaOCl. This coincides with previous studies,[34,35] showing that the precision of the Root ZX and iPex was not influenced by the presence of NaOCl.

Moreover, the results indicated that the existence of CHX in the canal did not influence the reading of both EALs, which coincides with the previous *in vivo* study of Ozsezer *et al*.[36] who reported more precision of WL estimation in the existence of CHX solution.

Despite a slight discrepancy in WL measurements, there were statistically no significant differences between canals irrigated with either CHX or NaOCl. However, there is still more precision of WL estimation for canals irrigated with CHX than with NaOCl. In accordance with Jenkins *et al*.[23] and Tekinarslan *et al*.,[37] they found that NaOCl has tendency to produce somewhat shorter WL. This may be due to the high electroconductivity nature and property of NaOCl which contains more ions and conductive components that ultimately decrease the impedance of EALs and cause a decrease in WL. On the other hand, low electroconductive irrigants tend to produce over-instrumentation.[37] This observation coincides with the research conducted by Reynoso *et al*.[38] which revealed that NaOCl had more conductivity than CHX. Additionally, Pilot and Pitts found that NaOCl had the highest conductivity among various endodontic solutions.[39]

Both ALs were less accurate with EDTA gel and solution. Gels are characterized by the following description: "Gels are mostly liquid, but because of their three-dimensional cross-linked structure, they perform as solids and, in their constant state, show no flow." As a result, gels have problems in electrical conductivities, which can be influenced by the gel's water content, ion concentration, and three-dimensional structure.[40]

Hems *et al*.[41] proposed the use of ozonated water to treat endodontic infections. During root canal irrigation, Nagayoshi *et al*.[42] discovered that ozonated water and 2.5% NaOCl had virtually the same antibacterial action, especially when combined with an ultrasonic instrument. It has been observed that the conductivity of ozonized water shows a slight increase (<0.1 unit) due to the process of ozonation. Both ALs in this study were unaffected by ozonated water and provided accurate readings with no significant difference between them.

Theoretically, the electrical conductivity of irrigation solutions inversely correlates with EALs accuracy; as ions and dissolved electrolytes increase, the electroconductivity will increase. However, it seemed that the problematic issue would be lessened with the use of the third and fourth generations of EALs. Therefore, the null hypotheses were accepted.

The existing research provides clues for the need for trustworthy instruments for WL estimation. The data outcome shows that clinically acceptable measurement can be achieved by using the EALs and the currently available irrigating solutions. Moreover, it is widely accepted that the presence of EALs can reduce the frequency of radiographs needed and can decrease the working time for endodontic practice. Such *in vitro* research offers a closed reality of the conditions in the oral cavity, and it is still challenging as the role of periodontium is excluded. Such research is imperative to be conducted as a new generation of EALs, and new types of irrigating solutions will be released into clinical practice.

Conclusions

Both Root ZX Mini (a third-generation AL) and iPex II (a fourth-generation AL) were used equally in the presence of NaOCl, CHX, ozonated water, EDTA (solution or gel), and a dry canal at 0.5 mm from the apex, regardless of their electrical conductivity.

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Conflicts of interest

There are no conflicts of interest.

Authors contributions

Each author made an equal contribution to the manuscript's preparation.

Ethical policy and institutional review board statement

The Research Ethics Committee at the University of Mosul's College of Dentistry approved this study.

Patient declaration of consent

It is not relevant because the research is *in vitro*.

Data availability statement

The data of the research results are accessible from the author (Dr. Eman M. Yahya, email: dremanmohammad@uomosul.edu.iq) on request.

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