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ORIGINAL ARTICLE

Effects of different irrigation solutions on the accuracy of electronic apex locators in curved and straight root canals

ABSTRACT

Aim: *To evaluate the effects of different irrigation solutions on the accuracy of 4 different electronic apex locators (Propex II, Propex-Pixi, Dentaport ZX, DTE Dpex V) (EALs) in curved and straight root canals.*
Methods: *A total of 20 extracted human teeth; 10 maxillary incisors with straight root canals and 10 mandibular molars with curved root canals, of which the curvature angles were between 30-50 degrees were selected. A #10 K-type file was advanced under a stereomicroscope at X15 magnification until the file was seen apically and the measured value was recorded as actual length (AL). Then, electronic length (EL) was determined using the selected EALs in different irrigation solutions. Group 1 was the control group. 1% NaOCl, 2.5% NaOCl, 5% NaOCl, 2% CHX, 17% EDTA and EDTA gel was used for groups 2-7, respectively. After each measurement, the roots were washed with 5 mL of distilled water and dried with a paper point before the same teeth were used in the next group. The difference was calculated by subtracting each tooth's AL from EL.*
Results: *When EALs accuracy was compared, there was a significant difference for Propex-Pixi and DTE Dpex V. When EALs' accuracy was compared in presence of different irrigation solutions, there was a significant difference in the Control group and Group 5.*
Conclusions: *All EALs performed more successfully in straight canals than in curved canals. Electronic measurements of molars with curved root canals were affected in the presence of CHX and when the root canals were dry.*

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Introduction

The establishment of correct working length (WL) has a critical role and can affect the success of root canal treatment (RCT). Appropriate shaping, disinfection, and filling of root canal could not complete without an accurate WL (1). Cemento-dentinal junction (CDJ) is a histologic landmark that determines where the pulp tissue ends and periodontal tissue begins (1). However, studies showed that most of the time CDJ and apical foramen are not at the same location (2, 3). The location of CDJ is accepted as 0.5-0.75 mm coronally to the apical foramen (4).

All the pulp tissue, necrotic materials, and microorganisms should be removed from entire root canal surfaces (4). Preparation and filling of root canal system at shorter than CDJ can increase undisinfected bacterial area causing failure of RCT. On the other hand, over-instrumentation beyond the WL damages apical constriction, making filling of the root canal system difficult jeopardize the apical seal (1).

While determining the WL operator can use radiographic methods, tactile sensation, and electronic apex locators (EALs) (5). Manual tactile sensation depends on the operator's skills, age of the patient and teeth type (6). The radiographic apex can be seen on the radiograph and identifies as anatomical end of the root (7). The distance between anatomical apex and radiographic apex distance can vary due to secondary dentin deposition. Disadvantages of using radiographs for determining WL are difficulty to set proper projection, radiation exposure and lack of possibility to reflect correct length of root. Both these methods are not objective and highly repeatable (8). For these purposes EALs, that use the resistance of electronic current passing, designed many years ago (9).

In the world of modern endodontics, EALs consider as valuable additions to determine WL (5). The development of EALs has helped to obtain more accurate WL and this method is highly predictable when combined with radiographs (10).

In 1918, Cluster suggested that the root canal length can be assess by using electrical conductance (11). In 1942, Suzuki reported a device that can measure electrical resistance between oral mucosa and periodontal ligaments (12). He discovered electrical resistance between file in the root canal and electrode positioned on the oral mucosa recorded a consist value of 6.5 kΩ. Later on, Sunada performed extensive experiments on patients and discovered that the electrical resistance between mucous membrane and periodontium was stable regardless of patients age, shape, or type of teeth (9).

First generation EALs, use resistance method for determining WL. Initially alternating current was 150 Hz sine wave and patients often felt pain due to this high current (7). Second generation EALs identify as single frequency impedance, that use impedance measurements instead of resistance. However, the impedance depends on vary factors and their biggest disadvantage was the need of constant calibration between each root (13). Third generation EALs use multiple frequency impedance different than second generation, it measures the impedance difference between 2 frequencies (7). Fourth generation EALs use multiple frequencies (2-5 frequencies), utilize resistance and capacitance measurements at the same time and allow more accurate measurement of WL different than third generation (14).

Propex II, and Propex-Pixi are the fifth generation EALs, Dentaport ZX is a third generation EAL, and Dpex V is a sixth generation EAL, all of which were used in this study. Propex II measures the capacitance and resistance seperetely, Propex Pixi measures the square root of the impedances, Dentaport ZX uses two different frequencies simultaneously and calculate the ratio of impedance and DTE Dpex V has multi-frequency apical position technology for accurate measurement.

In addition, irrigation solutions are essential for disinfecting the root canal system (15). Usage of these solutions provide lubrication, debridement and dissolution of tissues. However, presence of any kind of electrolytes can affect determination of WL of EALs (16). In particular, presence of

electroconductive solutions such as sodium hypochloride (NaOCl) reduces impadence, resulted in determining shorter WL (17).
Although there are limited studies in the literature showing the accuracy of EALs in teeth with curved roots, no study has been found investigating the comparison of the accuracy of different EALs in determination of WL in straight and curved root canal (10, 18).
The aim of this *in vitro* study was to evaluate the effects of different irrigation solutions on the determination of WL using with 4 different EALs (Propex II, Propex-Pixi, Dentaport ZX, DTE Dpex V) in teeth with straight and curved root canals were evaluated. The null hypothesis tested was that the irrigation solutions and canal curvatures do not affect the accuracy of different generation EAL measurements.

Materials and Methods

The Clinical Research Ethics Committee of Akdeniz University, Turkey reviewed and approved the study design with decision number KAEK-475. G*Power 3.1.9.7 program was used to the determine sample size. When the minimum clinical significant difference between success rate by EALs for each solution is predict to be 30%, the minimum number of samples to be included in this study with a .05 alpha value and 80% power is 41 for each EAL. A total of 20 extracted human teeth; 10 maxillary incisors with straight root canals and 10 mandibular molars (mesial roots) with curved root canals, of which the curvature angles were between 30-50 degrees were used.
After the teeth were examined under the operating stereomicroscope (Zeiss Stemi, CarlZeiss, Germany), teeth with cracks or fracture lines, or RCT were excluded from the study. Radiographs were taken in buccolingual direction from the mandibular molar teeth, and the angle of curvature of the root canal was determined according to the Schneider's method (19). Teeth with the curvature angles were between 30-50 degrees were selected.
Hard and soft tissue residues on the teeth were cleaned with a scaler. During the study to prevent the teeth from drying out, the teeth were stored in saline solution. The endodontic access cavities were prepared in all teeth. After checking the apical patency with the #8 K-file, the teeth with the #10 K-file stuck apically were selected. To create a stable and reliable coronal reference point incisal edges and cusps of included teeth were flattened.

Determination of Actual Length (AL)
#10 K-type file advanced under a stereomicroscope (Zeiss Stemi, CarlZeiss, Germany) at X15 magnification until it can be seen apically. The rubber stopper was fixed to the incisal edge at the first moment when the file was seen apically, and then the distance between the rubber stopper, which was removed from the canal, and the tip of the file, was measured with an endometer. This process was repeated 3 times by the same operatör for each tooth to prevent operator failures. The avarage value were calculated and recorded as the actual length (WL).

Determination of Electronic Length (EL)
Alginate was mixed according to the manufacturer's instruction. The lip clip of the EALs remained in the alginate and the teeth were embedded in the alginate model at the enamel-cement margin. Electronic length (EL) was determined using 4 different EALs (Propex II, Propex- Pixi, Dentaport ZX, DTE Dpex V).
The #10 K- file was advanced through the canal until the signs of *'Apex'* for Propex II (Dentsply, Ballaigues, Switzerland), *'0.0'* for Propex Pixi (Dentsply, Ballaigues, Switzerland), *'0.0'* for Dentaport ZX (Morita, Kyoto, Japan) and *'0.0'* for DTE Dpex V (Woodpecker, Guangxi, China) were seen on the screen of EALs.
After seeing these signs remained constant for 5 sec on the screen of the devices, the rubber stopper was fixed. Then the distance between the rubber stopper and file tip was measured with an endometer and the EL was recorded. This procedure was repeated for 7 groups for different irrigation solutions at different days. All measurements were performed by a single op-

erator by repeating 3 consecutive times for each tooth.

The irrigation solutions were freshly prepared and groups were divided according to the irrigation solution to be used. Measurements of ELs were obtained under dry condition and after irrigation with 5 mL of the solutions:

Group 1 (Control Group). In this group, after each teeth were dried with paper-points measurements of EL were recorded using 4 different EALs.

Group 2 (1% NaOCl). 5 mL of 1% NaOCl was used as irrigation solution in this group. EL measurements were recorded for this group using the same electronic measurement method.

Group 3 (2.5% NaOCl). 5 mL of 2.5% NaOCl was used as irrigation solution in this group. EL measurements were recorded for this group using the same electronic measurement method.

Group 4 (5% NaOCl). 5 mL of 5% NaOCl was used as irrigation solution in this group. EL measurements were recorded for this group using the same electronic measurement method.

Group 5 (2% CHX). 5 mL of 2% chlorhexidine (CHX) was used as irrigation solution in this group. EL measurements were recorded for this group using the same electronic measurement method.

Group 6 (17% EDTA solution). 5 mL of 17% EDTA was used as irrigation solution in this group. EL measurements were recorded for this group using the same electronic measurement method.

Group 7 (17% EDTA gel). 5 mL of 17% EDTA gel was used as irrigation solution in this group. EL measurements were recorded for this group using the same electronic measurement method.

After each irrigation solution, the roots were washed with 5 mL of distilled water and dried with a paper point before using the next solution.

Statistical Analysis

The difference was calculated by subtracting the WL from the EL for each tooth.

Negative values (-) indicated a shorter response than recorded value, and positive values (+) indicated a more advanced response from recorded value. In the statistical evaluation, it was investigated how much the differences between recorded value and EALs value and the obtained WL deviated from the resorption area (*0 points) and whether this deviation was significant. The accuracy of WL determination methods was compared within the tolerance range of ±0.5 mm. The possible differences between the percentages of acceptable measurements obtained by EALs was analysed by the chi-square test. In order to control for type 1 error, Bonferroni correction was used in pairwise comparisons using standard statistical software (SPSS 25.0). For all tests, the significance level was set to 5%.

Results

In this study, 10 mandibular molars with mesial root canal curvatures between 30-50 degrees and 10 maxillary incisors with straight root canals were evaluated with 4 different EALs. As shown in Table 1, a total of 70 measurements were recorded for 10 molars and 10 incisors in the presence of 7 different solutions. A significant difference was found for Propex-Pixi and DTE Dpex V. Propex-Pixi and DTE Dpex V were more successful in straight root canals than curved ones (P <0.05). There was no significant difference for Propex II and Dentaport ZX. Propex II and Dentaport ZX had more successful measurements in straight root canals than curved ones, with the success rate of 57.1% and 64.3%, respectively.

When EALs accuracy was compared in 40 measurements in presence of different irrigation solutions, there was a significant difference in the Control group and Group 5 (2% CHX) as is shown in Table 2. In these groups, EALs were found significantly more successful at incisors with straight root canals than at molars with curved canals (P <0.05). In other groups there was no significant difference. For incisor teeth, Group 7 (EDTA gel) had the most successful results with a success rate of 77.5% and Group 2 (1% NaOCl) had the lowest success rate (55%). For molars, Group 7 (EDTA gel) had the most successful results with a

Table 1

Comparison of the accuracy of four different EALs in curved molar and straight incisors in ± 0.5 mm tolerance range (with each device, 70 measurements were made for 10 molars and 10 incisors in the presence of 7 different solutions)

EAL	Molar		Incisor		p-value
	%	n	%	n	
Propex II	41.4%	29[a]	57.1%	40[a]	0.063
Propex-Pixi	54.3%	38[a]	74.3%	52[b]	0.014
Dentaport ZX	55.7%	39[a]	64.3%	45[a]	0.301
DTE Dpex V	48.6%	34[a]	70.0%	49[b]	0.010

*The lowercase letters indicate the difference between the molars and incisors for each EAL.

Table 2

Comparison of the accuracy of EALs in curved molar and straight incisors in ± 0.5 mm tolerance range according to the presence of different irrigation solutions (in each group, 40 measurements were made for 10 molars and 10 incisors with 4 EALs)

Group	Molar		Incisor		p-value
	%	n	%	n	
Control	42.5%	17[a]	67.5%	27[b]	0.025
1% NaOCl	42.5%	17[a]	55.0%	22[a]	0.263
2.5% NaOCl	57.5%	23[a]	62.5%	25[a]	0.648
5% NaOCl	52.5%	21[a]	57.5%	23[a]	0.653
2% CHX	37.5%	15[a]	75.0%	30[b]	0.001
17% EDTA	52.5%	21[a]	70.0%	28[a]	0.108
EDTA gel	65.0%	26[a]	77.5%	31[a]	0.217

*The lowercase letters indicate the difference between the molars and incisors within each group.

success rate of 65% and Group 5 (2% CHX) had the lowest success rate (37.5%).

Discussion

Apical constriction is generally a narrowest portion of the root canal system and may vary widely in shape. CDJ, the point where pulp tissue ends and periodontal tissue begins, is the ideal point for working length. However, CDJ and apical constriction could not always coincide. Therefore operators use various methods to obtain an accurate working length such as tactile sense, radiographic methods, or EALs (5). For this reason to evaluate the accuracy of EALs, the ± 0.5 mm tolerance range was accepted. This tolerance range is considered highly accurate and clinically acceptable by previous studies (20-23).
Materials used for the embedding of extracted human teeth should have similar electroconductive and colloidal consistency as the periodontal ligament.

Many studies used agar-agar, gelatin, alginate, or saline solution for *in vitro* EAL studies (16, 18, 34). Alginate models have favored materials because of their firm consistency that prevents intrusion of material, good electroconductive property, inexpensive and easy preparation. Also, the stiffness of alginate prevents fluid movement inside to canal that can cause premature electronic readings (18). Due to these advantages, alginate mold was used in this study to mimic as much as possible the periodontal tissue.

Irrigation solutions take an important role in RCT. However, there are still concerns that solutions may affect EALs accuracy (5, 24-29). NaOCl is the most popular and universally accepted irrigation solution with the capacity for disinfection and dissolution of organic tissue. NaOCl is commonly used in concentrations between 0.5% and 6% (30). On the other hand, CHX is generally used to disinfect the root canals and is commonly used in 0.2-2% concentrations and 17% EDTA is used as a chelator to remove the smear in routine RCT (31). Therefore, the most commonly used irrigation solutions were preferred in this study.

Khattak et al. (24) have reported CHX has a lesser effect than NaOCl on ProPex II. Ozsezer et al. (5) showed that in the presence of CHX solution, closer measurements to AL were obtained with ProPex II than in the presence of NaOCl. In another *in vitro* study by Jain et al. (26) evaluated the efficacy of Root ZX and Propex II in the presence of 1% NaOCl and 2% CHX, CHX had more successful measurements. Also, Khursheed et al. (25) obtained the best results in presence of CHX. In this study, successful measurements were obtained with the presence of CHX solution for incisors with straight root canals as well. However, the lowest success rate was obtained in Group 5 for molar teeth with curved root canals. This inconsistency may be explained by anatomical variation of molars.

In the presence of NaOCl solution, regardless of the concentration of the solution, WL measurements were the least successful. A possible explanation of these short measurements could be the high electroconductive property of NaOCl (27). Previous studies showed that solutions with high electroconductive properties reduce the impedance of EALs and cause a decrease in WL whereas low electroconductive solutions are caused by over-instrumentation (32, 33). Altunbaş et al. (34) have been reported similar results that the percentage of accurate results was found decreased in the presence of NaOCl solution. Kobayashi et al. (35), and Fan et al. (16) reported that high electroconductive solutions such as NaOCl can cause short measurements. On the other hand, previous *in vitro* studies (24, 29) indicated that the accuracy of EALs was not influenced by the concentration of NaOCl which is consistent with the results in this study.

Oliveira et al. (36) tested 5 different EALs including Propex-Pixi and ProPex II and indicated that the best results were obtained when the file reached to apical foramen without passing beyond this point. Therefore, the EL measurement was recorded at the point where the signal to reach the apical foramen was seen on the screen of EALs.

Somma et al. (37) compared the accuracy of Dentaport ZX, Raypex 5, and ProPex II and reported that there was no significant difference among EALs. This result for Dentaport ZX and ProPex II was in accordance with the present study. However, Mancini et al. (38) reported that Dentaport ZX showed less accuracy than ProPex II in the study that evaluated the accuracy of EALs in anterior and posterior teeth. In the present study, there was no significant difference between Dentaport ZX and Propex II. This inconsistency could be explained by the different experimental set-ups and conditions of the root canal system.

Sadeghi et al. (18) reported that successful measurements of actual WL with ± 0.5 mm tolerance range were 70% for straight canals and 35% for curved canals. Also, Wrbas et al. (39) reported that the determination of WL in anterior teeth with ± 0.5 mm tolerance range was 80%. These results are consistent with the present study. The accuracy of EALs decreased in curved posterior teeth. This situation can be clarified by reducing the taper and the diameter of an apical foramen in curved root canals affect the EL measurements.

Mandibular molar teeth are considered to have more apical variations and deltas. Keleş et al. (40) reported that mesial roots of mandibular molar teeth have apical deltas that can reach up to 2 mm. These anatomical variations are difficult to disinfect, later on can cause reinfection of the root canal system and also can affect working length determination of EALs.
In this study, there were statistically different results obtained among the irrigation solutions, canal curvatures, and EAL measurements. Therefore, the null hypothesis was rejected.
This study has some limitations such as the absence of intraoral electroconductive fluids and periodontal ligament due to its *in-vitro* setup. Although teeth had occlusion reduction in order to obtain a reference point, it is challenging to obtain similar WL within each tooth. Other limitations of this study are anatomical variations of extracted teeth and the difficulty of standardization of curvature angles. Even though the curvature angles are standardized with Schneider's method, it is difficult to obtain exactly a 30°-50° angle with extracted teeth.
In literature, there are few studies that focused on the accuracy of EALs on curved and straight root canals. Therefore, the results of this study should be verified by clinical studies.

Conclusions

All EALs used in the present study performed more successfully in straight canals than in curved canals, even though the only significant difference was found for Propex-Pixi and DTE Dpex V. In addition, electronic measurements of molar teeth with curved canals are adversely affected in the presence of CHX and when the root canals are dry.

Clinical Relevance

The accuracy of electronic apex locators is the most commonly used method for determining the working length in endodontic treatments, in the presence of different irrigation solutions and tooth types.

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Conflicts of interest

The authors have no declared financial interests in any company manufacturing the types of products mentioned in this article.

Ethics Approval

The Clinical Research Ethics Committee of Akdeniz University in Antalya, Turkey reviewed and approved the study design (decision number KAEK-475).

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