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Original Research

The Accuracy of Different Apex Locator Systems in Detecting Root Perforations in the Presence of Different Irrigation Solutions

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ABSTRACT

Objective: One of the most studied topics in electronic apex locators (EALs) is the effect of root canal condition on the accuracy of EALs. In this study, the accuracy of Root ZX Mini, Raypex 6, and Apex ID in detecting root perforation was evaluated in a dry environment and in the presence of saline, ethylenediamine tetraacetic acid (EDTA), and sodium hypochlorite (NaOCl) solutions.

Methods: The mesiobuccal roots of 64 human maxillary first molars were selected for the study. These root canals were perforated from buccal root surface using a #1 Freze Beutherlock Peeso to form a 0.4 mm cavity. After perforation, the area where #40 K type file appeared was recorded as the actual length (AL) and the length measured by EAL devices both in dry canals and in the presence of solutions was recorded as the electronic measurement (EL). All electronic measurements were statistically compared with the actual length.

Results: All EALs achieved AL-consistent results on EL measures. Consistency was determined using Root ZX Mini measurements in dry canals and canals irrigated with saline. The consistency of EL and AL conducted with Raypex 6 and Apex ID in canals irrigated with NaOCl, saline, and EDTA was found. There was a statistically significant difference in ELs with irrigation solutions among all EALs ($p<0.05$). In the dry environment, there was no statistically significant difference between the EALs ($p>0.05$). A consistency was discovered between ELs generated with the Root ZX Mini and ALs in both dry and saline-irrigated canals. Consistency was observed between ELs measured with Raypex 6 and Apex ID and ALs in canals irrigated with NaOCl, saline, and EDTA.

Conclusion: The accuracy rates of the EALs used in this research were 97%–100% in the 1 mm range and 83%–92% in the 0.5 mm range. Despite the fact that ALs and ELs differed statistically significantly at the 0.05 level, these variations weren't thought to be clinically relevant. In the presence of conditions with different electro conductors, EALs from different generations may be used safely, and in a range of canal situations, these devices can yield measurements that are most similar to the AL.

Keywords: Apex locator, Apex ID, Electro conductivity, Raypex 6, Root ZX.

INTRODUCTION

Root perforations are pathological connections that relate the root canal system to the exterior of the root and adjacent tissues by damaging the cementum tissue [1]. Perforations can be caused by deep caries or pathological apical conditions, although the majority of them are iatrogenically developed [2]. Root perforation is a significant problem occurring in 3-10% of endodontic procedures [3]. These inadvertent conditions may cause irritation and contamination of irrigation solutions or sealers, as well as debris created during endodontic treatment in connection to the afflicted area [4, 5]. Furthermore, inaccurate detection of the perforated region raises the possibility of procedural mistakes such as overinstrumentation and overfilling. When treating the perforated site, the time elapsed between perforation and treatment, as well as the size and location of the cavity, are critical. The prognosis is poor if the condition is not adequately assessed and treated, which could require tooth extraction [1]. It is critical to understand the location of the perforation so that root canal preparation, intracanal medicament administration, and perforation repair may be carried out correctly. Dental operation microscopy, endoscopy, optic coherence tomography, profuse bleeding from the root canal during instrumentation, examination of bleeding by paper points, and radiographic assessment are all possible methods for locating root perforations [5 - 7]. These approaches, however, have obstacles in practical applications. For example, in the presence of blood in the perforation area, a paper point may not always be able to identify the perforation zone. Furthermore, when perforation is in the buccal or palatal sides of the root, traditional radiographs have limited diagnostic value in some cases, such as overlapping anatomical structures, and radiopaque materials [8]. D'Addazio et al. spotted this pattern and reported that periapical radiography failed to identify the majority of perforations, resulting in inaccurate diagnosis in 20% of instances [9].

Main Points;

- It has been found that Root ZX Mini, Raypex 6, and Apex ID can be used safely for detecting root perforation, in a dry environment and in the presence of saline, EDTA, and NaOCl solutions.
- With this study to examine the accuracy of EALs with different root canal solutions, although there were differences between irrigated canal groups, there was no difference in a dry environment.

Electronic apex locator (EAL) is a non-invasive option supplementary to radiography for more precisely detecting the location of root resorptions [6]. According to Sunada's research, there is a continuous association between the electrical resistance of the oral mucous membrane and the periodontium; an EAL may assess perforation when it connects with the periodontal membrane and records a constant value [10]. Previous EALs were not particularly accurate in the presence of irrigation solutions because they work on resistance measurements between the root canal and the periodontal ligament (PDL) [11]. The most recent generation of EALs can detect impedances at numerous frequencies and function in both dry and wet canal environments [12]. The Root ZX Mini (J. Morita Corp., Tokyo, Japan) is a third generation EAL with a tiny, portable design that employs a proportional technique created by adapting the Root ZX [13]. Raypex 6 (VDW GmbH, Munich, Germany) is a multi-frequency EAL that is the fourth generation member of the Raypex series [7]. Apex ID (SybronEndo, Glendora, CA) is also a fourth generation EAL that works in the same way as Root ZX but at altered frequencies [14].

The importance of root canal irrigation during endodontic procedures cannot be overestimated. Endodontic irrigants widely employed for this purpose include sodium chloride solution (saline), ethylenediamine tetraacetic acid (EDTA), and sodium hypochlorite (NaOCl) [15]. Several investigations have found that irrigant in the root canal can impair EAL accuracy [7, 16]. The purpose of this study is to compare the detection accuracy of the Root ZX Mini, Raypex 6, and Apex ID under dry conditions and in the presence of 0.9% sterile saline, 5% NaOCl, and 17% EDTA. The null hypothesis was that there was no difference in the efficacy of the three EALs in finding root perforations under four separate canal conditions.

MATERIALS AND METHODS

The University Clinical Researches Ethics Committee authorized the research design (Approval number: 2017/369, date: 06.11.2017). All experimental procedures were carried out in matching with the World Medical Association Declaration of Helsinki, and all participants provided written informed consent. Using G*Power 3.9.1 software (Heinrich Heine University, Dusseldorf, Germany) and a previous study [15], a power calculation was performed to determine whether the expectation of a medium effect size (f=0.25) between measurements made with EALs in four different environments (dry condition-NaOCl-saline-EDTA) was statistically significant. The minimum number required in each category was 45 (α= 0.05; 1-β=0.80). A sample size of 64 teeth was selected for this study. The same samples were used for each irrigation solution and each EAL in all groups in order to ensure standardization in applications.

Sample Preparation

The study included 64 human maxillary first molar teeth extracted for orthodontic or periodontal reasons excluding teeth with root fractures, open apices, calcification, prior root perforations, and root resorption. To provide a consistent reference point for all measurements and to ensure a 15 mm root length, the mesiobuccal roots of these teeth were split with diamond burs (Diatech, Charleston, USA) under water cooling. A periodontal curette (Gracey curettes, Hu-Friedy, Chicago, USA) was utilized to remove calculus from the root surfaces. A stereomicroscope (Carl Zeiss, Gottingen, Germany) was employed to extensively examine the root at 20° mesial and distal angulation (OB Ç). Then the roots were disinfected for 48 hours at 4 °C in 5.25% NaOCl solution (Wizard, Rehber Kimya, Istanbul, Türkiye) and kept in 0.9% sterile saline solution (Polifarma, Istanbul, Türkiye) until use. The working length of each root canal was estimated to be 1 mm shorter than this measurement after the tip of a #15 K-file became observable in the apical foramen of the teeth (OB Ç). The canals were then instrumented with Reciproc (VDW, Munich, Germany) rotary instruments #25 and #40. During the instrumentation, 2.5 mL of 5.25% NaOCl (Wizard, Rehber Kimya, Istanbul, Türkiye) was administered to irrigate the canal, followed by 2.5 mL of distilled water. The canals were irrigated with 2 ml of 5.25% NaOCl followed by 2 ml of distilled water and dried with paper points (DiaDent Group, Chongju, Korea) after preparation.

Using a NSK F16R handpiece (NSK, Tochigi, Japan) and a #1 Freze Beutherlock Peeso (Mani Inc. Japan), the roots were artificially drilled towards the outside of the buccal root surface at a 90-degree angle. This point was at 4 mm from the anatomical apex and also at the outermost point of the root curvature. The cavities were approximately 0.4 mm in diameter. An electronic caliper (Mitutoya, Kawasaki, Japan) was used to measure the diameter of the artificial perforations. A #40 K-file was inserted and seen via the perforation site with a stereomicroscope (Carl Zeiss, Gottingen, Germany) at 4X magnification. The actual length (AL) of the canals up to the perforation area were measured to the nearest 0.05 mm with an electronic caliper by visualizing the tip of a #40 K type file at 20X magnification under the stereomicroscope (Figure 1). AL measurements were performed by two operators (OB Ç, E Ç) with ten years of expertise with EALs using various technologies, and the results were averaged to assure the accuracy of the measurements.

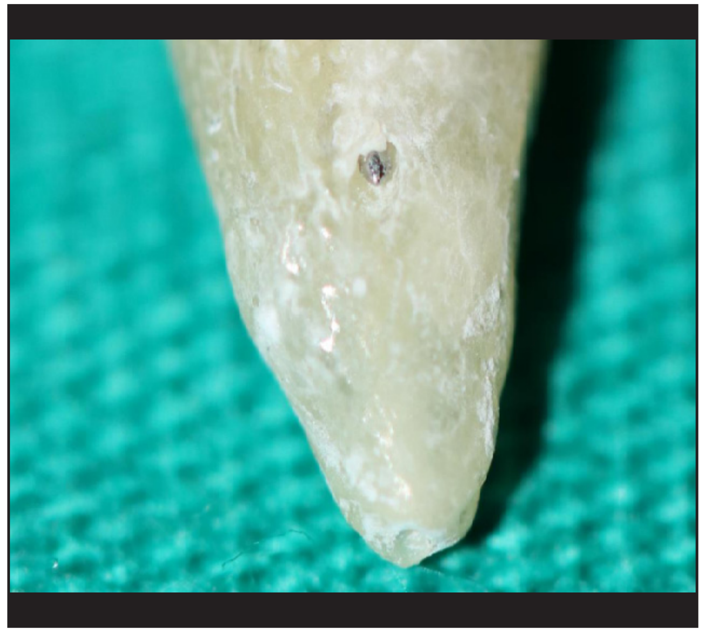

Figure 1. The hand file coming out of the perforated area

Alginate (Blueprint, Dentsply, UK) was poured into 20 mm deep silicone cylinder molds. The teeth were then inserted in this mold up to the cemento-enamel junction in order to simulate the PDL. To finish the electrical connection, a slot was cut on the edge of the alginate model for putting the lip clip. Apex locators were then employed in dry canal conditions and in irrigated conditions with 5.25% NaOCl (Wizard, Rehber Kimya, Istanbul, Türkiye), 0.9% sterile saline solution (Polifarma, Istanbul, Türkiye), and 17% EDTA (Werax, Izmir, Türkiye) respectively to digitally detect the perforation site using a #40 K type file. Two blinded evaluators (OB Ç, E Ç) examined the Root ZX Mini, Apex ID, and Raypex 6 readings in line with the manufacturers' electronic measuring (EL) instructions. Each EAL's EL measurements were also repeated twice, and their averages were recorded. The difference between the ELs and the AL of the perforations was also estimated by subtracting AL from EL. Negative and positive values indicated that measurements taken by EALs were short or long of the AL, respectively. As an intermediate irrigant, 2.5 ml of distilled water was utilized between each irrigant with a double side-port needle (31 gauge NaviTip Sideport; Ultradent Products Inc, South Jordan, UT, USA). The canals were then dried with paper points. This method was then repeated with different irrigant solutions introduced into the root canal before inserting the #40 K-file to locate the perforation site.

Statistical Analysis

The information was recorded using a computer software (Microsoft Office Excel 2010, USA) and double-checked for accuracy. The descriptive statistics for the study's data were mean and standard deviation (SD) for numerical variables. The Shaphiro Wilk test determined whether the data was suitable for normal distribution, and the paired t test compared the values of normally distributed variables across two techniques. Furthermore, intraclass correlation coefficients were calculated to assess measurement agreement between EALs. The difference between the measurements obtained in different EALs and settings and the real measurement was analyzed using analysis of variance. The Tukey test was employed to distinguish across experiment groups. SPSS 22.0 (SPSS Inc, Chicago, IL, USA) was used to conduct the analyses and tests. The significance level of p<0.05 was selected.

RESULTS

Table 1 shows the mean differences in perforation measures between EL and AL for the EALs employed in the study under varied canal circumstances, as well as the consistency between EL and AL. The study hypothesis was accepted because within the 95% confidence interval (p=0.001), all EALs in the study achieved AL-consistent results on EL measures. Table 2 presents the mean ELs and SDs of recorded from the EALs tested in the study under four separate canal conditions.

Consistency was determined using Root ZX Mini measurements in dry canals and canals irrigated with saline when the relationship between ALs and ELs was examined at the 0.05 significance level. The consistency of EL and AL conducted with Raypex 6 and Apex ID in canals irrigated with NaOCl, saline, and EDTA was also found (Table 1). In different root canal situations, there was a statistically significant difference in the ELs of the Root ZX Mini, Raypex 6, and Apex ID (p<0.05) (Table 1). However, in the dry environment, there was no statistically significant difference between the EALs (p>0.05). Furthermore, there was no statistically significant difference in EALs when NaOCl, saline, or EDTA were present (p>0.05). Table 1 also displays the EALs-canal conditions groups with 0.05 significant levels between ALs and ELs. A consistency was discovered between ELs generated with the Root ZX Mini and ALs in both dry and saline-irrigated canals. Consistency was also discovered between ELs created with Raypex 6 and Apex ID and ALs in canals irrigated with NaOCl, saline, and EDTA.

Root ZX Mini measurements in dry, NaOCl, EDTA, and saline were 83%, 88%, 89%, and 90% within the range of 0.5 mm, respectively. 97%, 100%, 97%, 100% success rates were recorded in the 1 mm range. Raypex 6 readings in dry, NaOCl, EDTA, and saline were 84%, 92%, 86%, and 90% within the range of 0.5 mm, respectively. 98%, 100%, 100%, and 100% success rates were recorded in the 1 mm range. Apex ID measurements in dry environment, NaOCl, EDTA, and saline were 89%, 92%, 86%, and 92% within the range of 0.5 mm, respectively. It was discovered to be 100% effective in all situations in the range of 1 mm.

Table 1. The mean difference between electronic lengths and actual length of the perforation with standard deviation for each electronic apex locator in different canal conditions (mm)

	Mean ± Standard Deviation				P value
	Dry condition	NaOCl	Saline	EDTA	
Root ZX Mini	0.12 ± 0.39^{a}	0.01 ± 0.3^{Bb}	-0.14 ± 0.3^{Bc}	-0.12 ± 0.38^{Bc}	0.001*
Raypex 6	0.07 ± 0.33^{c}	0.21 ± 0.29^{Ab}	0.31 ± 0.27^{Aa}	0.4 ± 0.34^{Aa}	0.001*
Apex ID	0.04 ± 0.31^{a}	-0.14 ± 0.3^{Cb}	-0.13 ± 0.27^{Bb}	-0.27 ± 0.33^{Cc}	0.001*
P value	0.460	0.001*	0.001*	0.001*	

*p<0.05; Analysis of Variance, Tukey posthoc test

A, B, C: Different superscript uppercase letters in the same column indicate statistically significant differences between electronic apex locators in the same environment.

a,b,c: Different superscript lowercase letters in the same row indicate statistically significant differences between environments in the same electronic apex locator.

SD, standard deviation

Saline, sterile sodium chloride solution

NaOCl, sodium hypochlorite

EDTA, ethylenediamine tetraacetic acid

Table 2. Mean and standard deviation values of electronic lengths measured with each electronic apex locators in different canal conditions (mm)

	Mean ± standard deviation			
	Dry condition	**NaOCl**	**Saline**	**EDTA**
Root ZX Mini	8.09±1.87	8.20±1.91	8.35±1.91	8.33±1.92
Raypex 6	8.14±1.89	8.00±1.89	7.90±1.90	7.82±2.06
Apex ID	8.17±1.92	8.35±1.94	8.34±1.93	8.48±1.97
Actual length	8.21±2.00			

Saline, sterile sodium chloride solution
NaOCl, sodium hypochlorite
EDTA, ethylenediaminetetraacetic acid

DISCUSSION

Root canal perforation may jeopardize periradicular tissue health and tooth retention. Radiographs can detect these tooth perforation sites. However, root perforations at the buccal or lingual side of the root surface are difficult to identify with 2-dimensional radiography methods [17], even for well-trained endodontists. Although attempts are made to overcome the shortcomings of 2D imaging, such as detecting dilacerations in the buccolingual direction with intraoral radiographs, cone-beam computed tomography (CBCT) is a more reliable 3-dimensional imaging approach for identifying perforation than periapical radiography, which eliminates these drawbacks [9, 18]. On the other hand, the radiation dosage produced by CBCTs precludes their widespread usage [19].

EALs, which have no side effects on tissue integrity, have been reported as a very accurate means of finding root perforation [5, 6]. In theory, in vitro models used to assess the accuracy of EALs have the problem of not fully reflecting in vivo research [20]. In reality, however, there is no statistical difference between research assessing EAL accuracy in vivo and in vitro circumstances, suggesting that in vitro models have produced solid results [21]. To imitate the electrical resistance of PDL, the mounting material must be similar to that of periodontal tissue. In in vitro studies of EALs on perforated roots, multiple dental embedding media such as agar, gelatin, sponge, alginate, and saline solution imitate the clinical situation [5, 6, 11, 22 - 24]. However, in ex vivo research, alginate revealed better results than other materials regarding EAL accuracy [24]. Alginate was preferred in the present study because it is an excellent electroconductive medium that remains around the tooth due to its colloidal gel form and mimics the periodontal situation [16]. In addition to these benefits, it is simple to handle and cheap [5, 25]. The alginate's solid consistency limits tooth movement and potential material penetration into the imitation perforation [24]. Furthermore, alginate endures around the root, preventing the operator from seeing the file tip, and thus offering reliable EL measurements [5, 24].

Although cavities with diameters ranging from 0.25 mm to 1.25 mm were recorded using EALs in earlier research [3, 6, 11, 26, 27], Shin et al claimed that artificial cavities wider than 1 mm could not properly imitate clinical root resorption situations [11]. Koç et al. found that EALs were successful in detecting artificial root cavities with sizes of 0.75 mm or more [28]. Similar to this study, several other investigations have indicated that the cavities with a diameter of less than 0.4 mm are ideal for EL measurements [11, 27, 29]. We considered the possibility that a greater cavity diameter may have an impact on the EALs' measurement accuracy and utilized larger cavities. EALs have been demonstrated to be accurate in identifying 1.5 mm perforations that may occur externally on the root surface as a result of post-placement intracanal treatments, resorption, and the use of larger files or coronal shapers. [30].

Previous investigations on the accuracy of Root ZX Mini, Raypex 6, and Apex ID in varied canal conditions revealed inconsistent findings. Furthermore, there was no agreement in the literature on the impact of varied canal conditions on the accuracy of Root ZX Mini and Root ZX, which is the original model of Root ZX Mini. Unlike Shin et al. and Srivastava et al., we observed that EL identified with Root ZX Mini in the presence of saline in the canal was consistent with AL [11, 29]. Similarly, Kaufman et al reported that in the presence of saline, the Root ZX Mini was more accurate in assessing working length of the canal [30].

Our findings, which were consistent with previous research, demonstrated that the presence of NaOCl in the canal influenced the EL detection of perforations by Root ZX Mini [11, 31]. This observation contradicted the findings of Bilaiya et al and Aydin et al [16, 32]. Shabahang et al showed that in the presence of NaOCl, the biggest divergence from AL in the measurements of Root ZX in the identification of the apical foramen occurred with NaOCl [33]. Several studies, on the other hand, concluded that NaOCl did not influence the ELs of Root ZX [34, 35]. In contrast to the research of Bilaiya et al and Aydin et al, the accuracy of the Root ZX Mini had been compromised in the current study [16, 32]. In our investigation, neither Raypex 6 nor Apex ID were able to measure the EL of perforations as well as Root ZX Mini in dry canal settings [31]. Also, ELs measured with the Root ZX Mini were greater in dry root canals than in irrigated root canals, comparable to the findings of Srivastava et al [31]. As noted by Bilaiya et al., the explanation for this circumstance could be that these EL measurement values were insufficient to have an impact on RootZX Mini's measuring performance [16]. However, other research also found that ELs were less reliable and unstable in dry canal environments because of Root ZX's reduced conductivity [29, 34]. Unlike the study conducted by Aydin et al., our current research's Raypex 6 results were impacted by dry circumstances but not by NaOCl or EDTA [32]. Comparisons were challenging since there was limited research on Apex ID's EL perforation measuring performance. Nonetheless, in 95% of the cases in which Koç et al. used saline to identify cavities with a diameter of 1.25 mm using Apex ID, the difference between EL and AL was between 0.0 and 0.50 mm [28]. This EL was determined to be 92% effective within a 0.5 mm range in the current investigation. The electroconductive qualities of the EALs we employed in our study under various canal circumstances most likely account for the discrepancies in the findings of their EL measurements. The capacity to conduct electricity is known as electrical conductivity, and it is based on the amount of dissolved ions present. Because of this, the aforementioned characteristic is exclusive to endodontic irrigation solutions and is also influenced by temperature and chemical composition. Differences in electrical conductivity within irrigating solutions influence not only the working length but also the EL of perforations [5, 11, 20]. The shape of the apical foramen may be one explanation for these inconsistencies. EL measurement performance of EAL might be affected by the structure and position of the main foramen [36]. Another explanation might be related to the principles on which these devices use, methodological variances, and operator competence [7, 13]. To ensure standardization, two endodontists with expertise in three distinct EALs with various technologies assessed the ELs in an alginate mounting model that allows for more exact measurements [6]. Also, we chose Raypex 6 and Apex ID which are fourth generation EAL in our study. The first reason was to compare the EL measurement performances of the perforation cavity between the same generation EAL using different frequencies. Secondly, there were few studies on EL determination of Apex ID.

The findings of this study, matching the literature, indicated that all three EALs were within the acceptable range. When analyzing the accuracy and repeatability of EAL measurements, literature noticed that SD was more essential than the difference between AL and EL, and that low SD suggested consistency of EALs [6, 35, 37]. The findings of research assessing the accuracy of perforation measurements of EALs were classified into acceptable error range tolerances of 0.5 or 1 mm [6, 11, 32]. In this research, the EL measurement in the dry environment of the Root ZX Mini had the lowest success rate (83%) in the 0.5 mm tolerance range, whereas the EL measurement of Raypex 6 in the presence of NaOCl and Apex ID in the presence of NaOCl and saline had the greatest success rate (92%). The EL readings of the Root ZX Mini in a dry environment and EDTA had the lowest success rate (97%) within the tolerance range of 1mm. Apex ID EL readings were 100% successful in all conditions, Raypex 6 in all irrigation solutions except dry, and Root ZX in NaOCl and saline. The lowest mean difference between EL and AL (0.01± 0.3) was measured in Root ZX Mini in the presence of NaOCl, and the greatest mean difference (0.4 ±0.34) was observed in Raypex 6 in the presence of EDTA. Aydin et al. discovered that the average distance from the tip of the file to the root canal perforations for Root ZX Mini was from 0.11 to 0.31 and 0.22 to -0.18 for Raypex 6 [32]. However, in our study, these values ranged from 0.01 to -0.14 and 0.07 to 0.4. The probable explanations for the difference might be that the artificial cavity constructed in their investigation was 1 mm in diameter, and they employed a Qmix solution containing substances with different electrical conductivities rather than saline [32]. Extrapolating these findings to real-life situations, it is possible to conclude that these irrigation solutions are difficult to keep in the perforation region, and the material employed to simulate PDL may not be as resistant as natural PDL. As a result, more in vivo studies are necessary for comparing these findings with other clinical scenarios.

Limitations

Firstly, 1.5 mm cavity diameter used in past studies may not be clinically appropriate since a study reports that perforations of 1 mm and greater may not properly reflect the actual situation (11). Perforation defects bigger than 1.5 mm, on the other hand, are clinically likely for a variety of reasons. Secondly, the conductivity of an irrigation fluid is proportional to its concentration (28). As a result, if we had chosen alternative concentrations in our study, we may have received different results. Thirdly, the fact that the EALs in our in vitro investigation were in contact with alginate impression material rather than real tissues most likely influenced the modeling of clinical situations. Furthermore, the lack of electro-conductive substances in the oral condition, such as blood and saliva, in the experimental setting may have resulted in differing EL values.

CONCLUSIONS

In the current study, the EALs employed exhibited an accuracy rate of 97%-100% in the 1 mm range and 83%-92% in the 0.5 mm range. Although there were statistically significant differences between ALs and ELs, these differences were not assessed as clinically meaningful. EALs of various generations may be used safely in the presence of various electro conductors and root canal irrigation solutions, and measurements closest to the AL can be obtained with these devices in a variety of canal circumstances.

Conflict of interest: None declared.

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Informed Consent: Received.

Ethical Approval: The Gaziantep University Clinical Researches Ethics Committee authorized the research design (Approval number: 2017/369, date: 06.11.2017).

Author Contributions: Conception: Ç, OB; A, U - Design: Ç,OB - Supervision: Ç,E; A,U - Fundings: Ç, E; A, U -Materials: Ç,OB - Data Collection and/or Processing: Ç, OB; Ç, E - Analysis and/or Interpretation: Ç, E; A, U - Literature: Ç, E; - Review: Ç, E; A, U - Writing: Ç, E - Critical Review: A, U.

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