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Evaluation of heated sodium hypochlorite's effect on the accuracy of contemporary electronic apex locators: an in vitro study

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Abstract

Background Accurate determination of the working length (WL) is essential for successful root canal therapy. Although electronic apex locators (EALs) are widely used for this purpose, the impact of irrigant temperature on their precision remains poorly understood. Therefore, in this study, we investigated the effect of variations in sodium hypochlorite (NaOCl) temperature on the performance of modern EALs, with particular emphasis on the recently introduced EAL, Ai-Pex.

Methods Twenty extracted human teeth were embedded in alginate to simulate clinical conditions. WL was measured using four EALs (Root ZX Mini, Propex Pixi, Raypex 6, and Ai-Pex) under three NaOCl temperature conditions: 19.4 °C (± 1.5 °C), 36 °C, and 70 °C. A dental operating microscope was used to determine the actual working length (AWL). Deviations between electronic and AWLs were recorded, and statistical analyses were conducted using repeated-measures analysis of variance (ANOVA) and chi-square tests.

Results All EALs exhibited high accuracy, with deviations within ± 0.5 mm of AWL across all NaOCl temperature conditions ($p > 0.05$). Ai-Pex achieved 95% accuracy at room and body temperatures and 100% accuracy at 70 °C. Similarly, Root ZX Mini, Propex Pixi, and Raypex 6 demonstrated consistent performance, with no statistically significant differences in accuracy across temperature groups.

Conclusions This study confirms that variations in NaOCl temperature do not significantly impact the accuracy of EALs in determining the WL for root canal therapy. These findings underscore the reliability of contemporary EALs under different clinical conditions, including the newly evaluated Ai-Pex. Further, in vivo studies are necessary to validate these results.

Keywords Electronic apex locator, Working length, Sodium hypochlorite, Irrigation temperature, Ai-Pex, Root ZX Mini, Propex Pixi, Raypex 6

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Background

The success of root canal therapy (RCT) depends on the complete removal of infected tissue, necrotic debris, and biofilms from the root canal system, followed by precise canal filling [1]. A critical determinant of successful RCT outcomes is the accurate establishment of the working length (WL) [2]. Traditionally, radiographic imaging and patient pain response were employed for this purpose [3]. However, these methods often fail to identify the true apical terminus due to the limitations of two-dimensional imaging [4].

Electronic apex locators (EALs) have revolutionized the field of endodontics by providing a reliable alternative to traditional radiographic methods [5]. These devices enhance procedural efficiency and reduce patient radiation exposure [3, 5, 6].

Since the initial introduction of EALs, which operated on direct electrical current and resistance principles, successive generations have been developed [7, 8]. Modern EALs now rely on alternating current at multiple frequencies and impedances rather than resistance [9]. Among these devices, the Root ZX (J Morita, Tokyo, Japan), which calculates the ratio of the impedances of two specific frequencies (0.4 and 8 kHz) for determining the position of the file within the canal [10], is widely regarded as the gold standard and one of the most extensively studied EALs [11, 12]. The Root ZX Mini offers the same level of precision in a more compact design [13]. The Propex Pixi (Dentsply Maillefer, Ballaigues, Switzerland) is a multi-frequency EAL that detects the sudden change in impedance upon reaching the minor apical foramen [11]. Raypex 6 (VDW, Munich, Germany), the latest model in the Raypex series, employs advanced multi-frequency measurement technology [14]. Ai-Pex (Woodpecker Medical Instrument Co., Guilin, China) is a recently introduced EAL that is equipped with advanced multi-frequency impedance measurement technology. In addition to its electric pulp testing capability, the device incorporates a United States-manufactured central processing chip integrated with a Digital Signal Processing module, to improve the accuracy and stability [15]. Ai-Pex also supports automatic calibration upon startup, and when connected to compatible endodontic motors, it enables real-time monitoring of WL during canal preparation [15].

Numerous studies have investigated whether factors such as instrument type and diameter, the presence of open apices or perforations, and the type and concentration of irrigation solutions influence the accuracy of EALs [16–21]. Irrigation plays a crucial role in RCT by facilitating the removal of dentine debris, tissue remnants, and microorganisms [22]; therefore, the WL is often determined in the presence of irrigation solutions [23]. Sodium hypochlorite (NaOCl), the most commonly used endodontic irrigant due to its antibacterial properties [24], is known to significantly reduce impedance because of its electrolytic conductivity [19, 21, 25]. Therefore, various studies have explored the impact of NaOCl on the performance of EALs [19–21].

Several techniques, including solution concentration, agitation, prolonged working time, and the use of preheated solutions, have been proposed to enhance the efficacy of NaOCl [24, 26]. Preheating NaOCl accelerates tissue dissolution and increases its antibacterial activity [22]. However, using preheated solutions may elevate the temperature of surrounding periodontal ligament tissues, raising concerns about potential bone damage, which is reported to occur at temperatures exceeding 47 °C [27]. De Santis et al. demonstrated that extraorally heated NaOCl at 70 °C, when introduced into the canal, increased the external root surface temperature to a maximum of 44 ± 2.5 °C [28]. In addition to its biological effects, temperature variations can alter the electrical conductivity of the solution [29], increase chlorine content, and accelerate the decomposition of unstable hypochlorite anions into chlorate and chlorine ions, potentially affecting measurements and influencing the response of EALs [30]. Previous studies have investigated the impact of preheated solutions on the fracture resistance of root dentin and the possible effect on dentinal tubule penetration [24, 31]. Nevertheless, the effects of different temperatures on EALs remain insufficiently investigated [30].

To our knowledge, no previous article has compared the accuracy of the recently introduced Ai-Pex with that of other latest-generation EALs, and research evaluating the impact of preheated NaOCl on EALs is limited. In this study, three specific temperatures were selected based on previous literature and their potential clinical implications: room temperature (19.4 ± 1.5 °C) to represent ambient conditions [26], body temperature (36 °C) to simulate intraoral conditions [32], and a preheated solution at 70 °C, selected considering the critical threshold below which no thermal damage to alveolar bone is expected [24, 28]. This study aimed to assess the effect of unheated and preheated NaOCl on the accuracy of electronic measurements of the WL and to compare the precision of four EALs: Root ZX Mini, Propex Pixi, Raypex 6, and Ai-Pex.

Methods

Ethics approval and guidelines

This study was approved by the Ethics Committee of the Faculty of Dentistry at Istanbul University (2024/60). All procedures adhered to the 2021 PRILE (Preferred Reporting Items for Laboratory Studies in Endodontology) and CRIS (Checklist for Reporting In Vitro Studies) guidelines [33, 34].

Sample size calculation
The required sample size was determined using the G*Power analysis program. To detect statistical significance with 95% power and a 5% type I error [20], a minimum of 20 samples per group was required.

Teeth selection
Twenty single-rooted, straight, mature human maxillary central incisors freshly extracted for orthodontic reasons or due to periodontal disease, were selected. The exclusion criteria included teeth with surface cracks, structural defects, root canal calcifications, increased curvatures, open apices, restorations, fractures, or previous endodontic treatments. These evaluations were assessed using an operating microscope (Leica M320; Leica Microsystems, Wetzlar, Germany) at x25 magnification. Root canal anatomy was evaluated using periapical radiographs taken in both buccolingual and mesiodistal directions. Samples were initially stored in 0.5% chloramine-T solution (Merck, Darmstadt, Germany) for 48 h to prevent contamination. Soft tissue residues and calculi were removed from the root surfaces using an ultrasonic scaler, after which samples were transferred to 0.9% sterile saline solution to prevent dehydration until use.

The crown portion of each tooth was sectioned at the cemento-enamel junction using a diamond disc, creating a flat surface to ensure reproducibility. Access cavities were made using round and fissure diamond burs, following standard clinical protocols. To facilitate access to the canal and provide a reservoir for irrigation, preflaring was performed using a HyFlex EDM 25/0.12 Orifice Opener (Coltene/Whaledent, Altstätten, Switzerland) [35]. Each tooth was assigned a numerical identifier (1-20) for identification.

The total length of each #10 and #15 K-file (M-access, Dentsply, Maillefer, Switzerland), defined as the distance from the base of the file handle to the file tip, was measured using a digital caliper (150 mm digital caliper, Alpha tools®, Oakland, NJ, USA) with an accuracy of 0.01 mm. Using a x25 magnification dental operating microscope, canal patency was confirmed by advancing #10 and #15 K-files into the root canal until the file tip became visible at the major apical foramen. A rubber stop was placed on a flat coronal reference point and secured with flowable composite resin to prevent movement. The file was carefully withdrawn, and the distance from the base of the handle to the base of the silicone stopper was measured. This value was subtracted from the total file length [10]. Each measurement was performed three times, and the actual working length (AWL) was determined as the mean of the three recorded values.

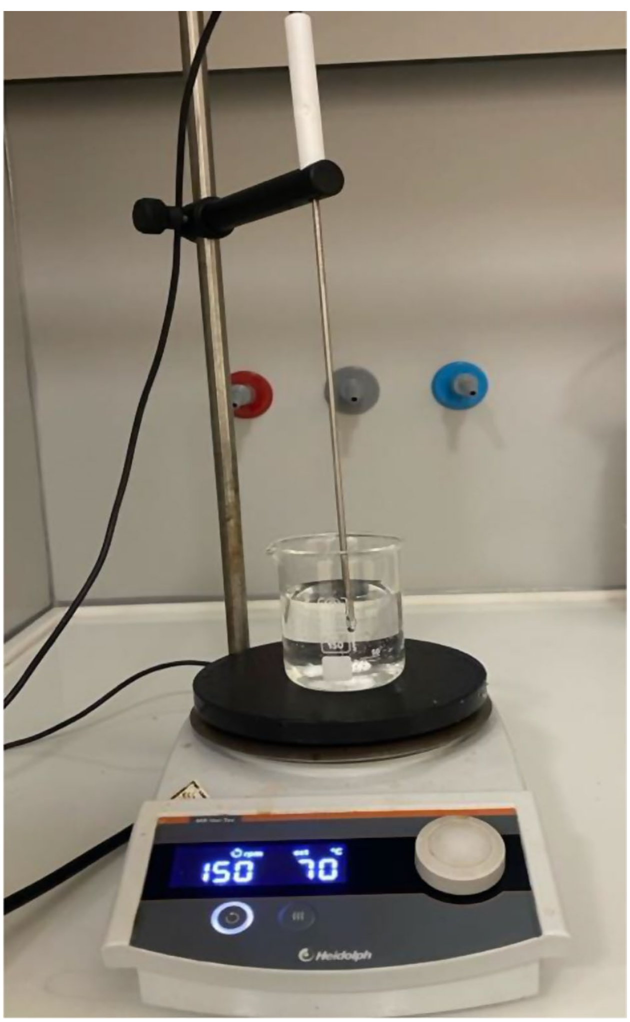

Fig. 1 Sodium hypochlorite solution being heated using a digital hot plate magnetic stirrer device (Heidolph MR Hei-Tec)

Experimental procedures
The procedures were performed at the Istanbul Medeniyet University, Science and Advanced Technologies Research Center. Samples were embedded in an alginate model within individual plastic containers, leaving 2 mm of the root surface exposed to simulate the electrical conductivity of the periapical tissues. Alginate was mixed according to the manufacturer's instructions and allowed to set.

Three series of irrigation solutions were introduced into the root canal according to the temperature of NaOCl (Chloraxid 5.25%, Cerkamed, Poland) (Fig. 1):

- 5.25% NaOCl at 19.4 °C (± 1.5 °C).
- 5.25% NaOCl at 36 °C.
- 5.25% NaOCl at 70 °C.

A digital hot plate magnetic stirrer (Heidolph MR Hei-Tec, Schwabach, Germany) equipped with a PT1000 immersion temperature sensor was used to heat and maintain the NaOCl solutions at constant temperatures.

To ensure uniform temperature distribution, 25 mL of 5.25% NaOCl was placed in a glass beaker and continuously stirred at 150 rpm using a PTFE-coated magnetic stir bar. During the procedure, when transitioning to different temperature stages, the solution was maintained at the target temperature for at least 30 s before each EAL measurement to ensure thermal stability. The room temperature solution had a mean temperature of 19.4 °C (± 1.5 °C).

Electronic measurements of the root canal length were performed using four different EALs (Fig. 2).

- Root ZX Mini.
- Propex Pixi.
- Raypex 6.
- Ai-Pex.

All measurements were performed by a single experienced operator, ensuring procedural consistency throughout the study. The samples were initially irrigated with 1 mL of saline solution and then dried using paper cones adapted to the canal before the experiment began. During the experiment, the unheated NaOCl solution at 19.4 °C (± 1.5 °C) was used first. Once the experiment with 19.4 °C (± 1.5 °C) NaOCl was completed for each specimen, the same procedures were repeated using 36 °C NaOCl and then 70 °C NaOCl, respectively. To minimize the cooling effect, a fresh solution was rapidly introduced into the root canals before each EAL measurement, and the measurements were promptly completed. At each measurement, the initially applied irrigation solution was aspirated, and the canal was blotted with a paper point to prevent temperature fluctuations.

Each root canal was irrigated with 1 mL of NaOCl solution using a 5 mL syringe fitted with a 30-gauge needle (Ultradent Products Inc., South Jordan, UT, USA). The pulp chamber was drained of excess irrigation solution using paper points, ensuring the root canal remained wet. The teeth were then gently dried using a cotton pellet.

A fresh NaOCl solution was introduced into the canal before each EAL measurement. A size 15 K-file, secured in the file holder of the EAL, was inserted into the canal, and the lip clip was placed in contact with the alginate mold. All electronic measurements were conducted within 2 h to maintain adequate humidity levels in the alginate, consistent with previous studies [12, 17]. The Root ZX Mini, Propex Pixi, Raypex 6, and Ai-Pex EALs were used following the manufacturers' specifications. The #15 K-file was affixed to the file holder of the EAL and advanced until the flashing bar displayed '0.0', indicating the location of the major foramen, as per the manufacturers' guidelines. The measurement was considered valid if the instrument remained motionless for at least 5 s. A rubber stop, fixed to the file using a flowable composite resin, marked the reference point of each sample. The electronic working length (EWL) was determined using a digital caliper, following the same protocol used for the AWL after file removal. Each EAL measurement was repeated three times under identical conditions, and the average reading was recorded as the EWL. The difference between the EWL and AWL was calculated, with negative values indicating EAL measurements shorter than the AWL and positive values indicating EAL measurements longer than the AWL. A zero value represented overlapping measurements.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics 22. The normality of the data was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests, which confirmed a normal distribution. Descriptive statistics were applied. One-way analysis of variance (ANOVA) was used for intergroup comparisons, whereas repeated-measures analysis was performed for within-group comparisons. Qualitative data between groups were analyzed using the Fisher–Freeman–Halton exact chi-square test, while Cochran's Q test was applied for within-group comparisons. Statistical significance was set at $p < 0.05$.

Results

The standard deviation (SD) values for each EAL and the mean difference between AWL and EWL at varying temperatures are summarized in Table 1. No statistically significant differences were observed in deviation rates within ± 0.5 mm from the AWL among Propex Pixi, Root

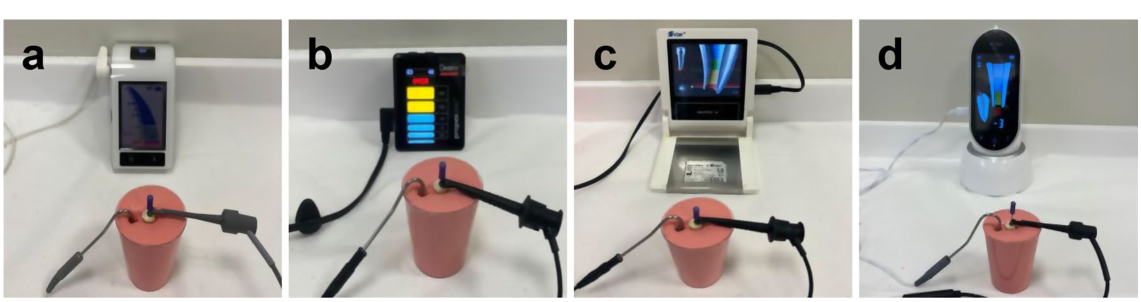

Fig. 2 The experimental setups used in measurements with EALs are as follows: **a**;Root ZX Mini, **b**;Propex Pixi, **c**;Raypex 6, **d**;Ai-Pex

Table 1 Means and SD of different EALs at various temperatures

	19.4 °C (± 1.5 °C)	36°	70°	
	Mean ± SD (Min/Max)	Mean ± SD (Min/Max)	Mean ± SD (Min/Max)	^{2}p
Root ZX Mini	-0.10 ± 0.2000 (-0.6/0.32)	-0.18 ± 0.25 (-0.65/0.45)	-0.16 ± 0.19 (-0.55/0.28)	0.265
Propex Pixi	-0.11 ± 0.29 (-0.57/0.54)	-0.20 ± 0.23 (-0.52/0.31)	-0.17 ± 0.24 (-0.67/0.25)	0.370
Raypex 6	-0.11 ± 0.25 (-0.44/0.67)	-0.24 ± 0.23 (-0.58/0.30)	-0.15 ± 0.26 (-0.52/0.46)	0.113
Ai-Pex	-0.10 ± 0.23 (-0.55/0.43)	-0.10 ± 0.22 (-0.42/0.40)	-0.09 ± 0.20 (-0.44/0.20)	0.980
^{1}p	0.995	0.272	0.682	

[1]Oneway ANOVA Test [2]Repeated Measures Analysis of Variance

Table 2 Comparative accuracy of EALs at different NaOCl temperatures

		Root ZX Mini (*N* = 20)	Propex Pixi (*N* = 20)	Raypex 6 (*N* = 20)	Ai-Pex (*N* = 20)
Heated	**Distance (mm)**	***n* (%)**	***n* (%)**	***n* (%)**	***n* (%)**
19.4 °C ± (1.5 °C)	<-0.51[a]	1 (5)	2 (10)	0 (0)	1 (5)
	-0.50 to 0.0 [a]	14 (70)	10 (50)	16 (80)	13 (65)
	0.01–0.5	5 (25)	7 (35)	3 (15)	6 (30)
	> 0.51	0 (0)	1 (5)	1 (5)	0 (0)
36°C	<-0.51 [a]	1 (5)	0 (0)	4 (20)	1 (5)
	-0.50 to 0.0 [a]	15 (75)	16 (80)	14 (70)	14 (70)
	0.01–0.5	4 (20)	4 (20)	2 (10)	5 (25)
	> 0.51	0 (0)	0 (0)	0 (0)	0 (0)
70°C	<-0.51 [a]	1 (5)	0 (0)	1 (5)	0 (0)
	-0.50 to 0.0 [a]	15 (75)	16 (80)	14 (70)	11 (65)
	0.01–0.5	4 (20)	4 (20)	5 (25)	9 (45)
	> 0.51	0 (0)	0 (0)	0 (0)	0 (0)

[a]Negative value indicates short (or coronal) file position in relation to the apical foramen

ZX Mini, Ai-Pex, and Raypex 6 under the tested temperature conditions ($p > 0.05$) (Table 1).

Root ZX Mini demonstrated deviations of -0.10 ± 0.20 mm, -0.18 ± 0.25 mm, and − 0.16 ± 0.19 mm at 19.4 °C (± 1.5 °C), 36 °C, and 70 °C, respectively. Similarly, Propex Pixi exhibited minor deviations from the AWL, with mean differences of -0.11 ± 0.29 mm at 19.4 °C (± 1.5 °C), -0.20 ± 0.23 mm at 36 °C, and − 0.17 ± 0.24 mm at 70 °C. Raypex 6 displayed deviations of -0.11 ± 0.25 mm at 19.4 °C (± 1.5 °C), -0.24 ± 0.23 mm at 36 °C, and − 0.15 ± 0.26 mm at 70 °C. Ai-Pex maintained the most consistent accuracy, with deviations of -0.10 ± 0.23 mm, -0.10 ± 0.22 mm, and − 0.09 ± 0.20 mm across the same temperature conditions (Table 1).

With a tolerance range of ± 0.5 mm, the accuracy of each EAL at different temperatures is detailed in Table 2. Root ZX Mini maintained a consistent accuracy of 95% across all temperatures. Propex Pixi exhibited an accuracy of 85% at 19.4 °C (± 1.5 °C), increasing to 100% at 36 °C and 70 °C. Conversely, Raypex 6 displayed variable accuracy, measuring 95% at 19.4 °C (± 1.5 °C), decreasing to 80% at 36 °C, before returning to 95% at 70 °C. Ai-Pex achieved 95% accuracy at 19.4 °C (± 1.5 °C) and 36 °C, increasing to 100% at 70 °C.

Discussion

WL determination during RCT increasingly relies on EALs [36]. Technological advancements continue to enhance EAL accuracy, prompting numerous studies in this field [6, 10–14, 16–21]. Evaluating EAL concordance with WL in in vitro investigations, particularly those using extracted teeth, requires an appropriate reference standard [17]. In this study, as radiographs are known to be less reliable in determining the AWL when the apical foramen opens laterally [17, 37], a dental operating microscope (x25) was used instead of periapical radiographs for comparisons. Moreover, the dental operating microscope is a widely recognized and frequently utilized method for determining WL in comparable studies [17, 20, 38].

In this study, teeth were embedded in alginate, a well-established in vitro medium that closely mimics the natural oral environment, enabling effective simulation of EAL performance during RCT [39]. Alginate provides an optimal conductive medium for the electrical circuit, facilitating connectivity between the file clip within the root canal and the lip clip affixed to the alginate [36, 38, 39].

NaOCl is a commonly used irrigation solution in chemomechanical preparation, with concentrations ranging from 0.5 to 5.25%. It is preferred for its antibacterial properties, lubricating action, debris removal capacity, and high pH [24, 40]. The efficacy of NaOCl depends on several factors, such as concentration, agitation, contact duration, and temperature [26]. The impact of NaOCl's high electrical conductivity on EAL accuracy remains a topic of debate [19, 41]. Due to its conductive properties, NaOCl has been the subject of several studies, which aim to determine whether its concentration influences EAL effectiveness [19, 20, 23]. Research suggests that while NaOCl at varying concentrations may slightly affect the accuracy of some devices, it does not significantly impact overall EAL performance and reliability [19, 20, 23]. Some researchers attribute this to the high electrical conductivity of NaOCl, which penetrates dentinal tubules, reduces the electrical impedance of canal walls, and enhances electrical contact with periapical tissues [19, 21, 25, 42].

Electrical conductivity varies with temperature fluctuations. As temperature increases, the kinetic energy of ions in the electrolyte solution rises, facilitating ion movement and generally enhancing electrical conductivity [29]. Therefore, in this study, we investigated the potential impact of temperature variations on EAL accuracy, considering the electrical conductivity of preheated NaOCl solutions. The accuracy of Root ZX Mini, Propex Pixi, Ai-Pex, and Raypex 6 in determining the WL at these specified temperatures was evaluated and compared. The findings indicate that, within a ± 0.5 mm and ± 1 mm margin of error, 5% NaOCl at different temperatures does not significantly affect EAL performance ($p > 0.05$). This suggests that EALs provide clinically accurate measurements in the presence of NaOCl, regardless of temperature variations, indicating that temperature fluctuations do not significantly affect electrical conductivity at low currents. De Hemptinne et al. reported that NaOCl irrigation solutions injected at varying temperatures rapidly equilibrate to body temperature 35.1 °C ± (1.0 °C) within the root canal [32]. For instance, a solution initially heated to 66 °C ± (1.6 °C) cooled to 37 °C within 1 min and further to 35.7 °C within 4 min. Similarly, a solution at room temperature warmed to 34.2 °C after 1 min and 35 °C after 4 min [32]. The findings of this study align with those of De Hemptinne et al., who demonstrated that NaOCl irrigation solutions injected at varying temperatures rapidly equilibrate to body temperature within the root canal. This suggests that temperature variations have a minimal effect on the accuracy of EALs, indicating that clinicians can confidently determine the WL even when using heated NaOCl to enhance its antimicrobial and tissue-dissolving properties. Furthermore, it may be inferred that adjunctive techniques that increase intracanal temperature, such as intracanal heating and passive ultrasonic irrigation [43], are also unlikely to compromise the reliability of EALs. However, our findings contrast with those of Baruah et al., who evaluated the accuracy of Root ZX Mini and Propex II using 5% NaOCl at room temperature and 60 °C [30]. In their study, the teeth were immersed in 5% NaOCl for 6 h [30], which may have altered the dentinal structure [44] and electrical conductivity. In contrast, our study used 0.5% chloramine-T solution followed by saline to better preserve the natural properties of dentin [44]. Additionally, Baruah et al. did not specify the heating protocol of the irrigant [30]. Furthermore, their study employed a 23-gauge needle [30], which may have limited access to the apical region [45]. In our study, however, a 30-gauge needle was used, which is commonly recommended in endodontic procedures for effective apical penetration, and is considered to provide more reliable measurements [45]. These methodological differences may account for the discrepancies between the two studies.

A ± 0.5 mm margin of error is widely accepted as a clinically reliable threshold [13, 14, 20, 23, 46]. In our study, considering a deviation of 0.5 mm from the actual length, the accuracy was 95% for Root ZX, 85–100% for Propex Pixi, 95–100% for Ai-Pex, and 80–95% for Raypex 6, demonstrating high precision. Compared with previous studies where WL was determined using an operating microscope and ± 0.5 mm reliability was analyzed, our findings were similar to results for Root ZX Mini, Propex Pixi, and Raypex 6 [14, 20, 47]. EALs utilizing multi-frequency technology have been shown to minimize measurement errors, enhancing WL determination accuracy [47, 48]. Our results corroborate the findings of previous literature, demonstrating the consistent performance of these devices across various clinical conditions [14, 20, 47, 48]. Notably, this study is the first to evaluate the accuracy of Ai-Pex, which exhibited a high success rate comparable to that of Root ZX Mini, Propex Pixi, and Raypex 6. The consistent performance of Ai-Pex at temperatures up to 70 °C indicates that it may also be reliable in clinical protocols involving preheated irrigation solutions. This finding is particularly relevant for clinicians who prefer to use heated NaOCl to enhance its antibacterial efficacy and tissue-dissolving capacity. In this respect, Ai-Pex stands out as an effective and reliable device for WL determination across various temperature conditions.

This study has some limitations. First, the sample size was relatively small (20 teeth) despite being based on a power analysis. Although this number was sufficient to detect statistically significant differences, it may limit the generalizability of the findings. Another limitation is the difference between simulated and clinical conditions. EALs do not interact with live tissue, lack exposure to electrically conductive fluids such as saliva and blood, and the electrical resistance of the periodontal ligament may differ from that of alginate, i.e., the simulation material used. To enhance and validate these findings, non-invasive methods such as finite element analysis are recommended. Additionally, future studies could explore the potential effects of preheated NaOCl on dentinal structure and its interaction with EALs to provide a better understanding. Nevertheless, further in vivo studies are required to confirm these results under more complex and dynamic clinical scenarios.

Conclusion

This study demonstrated that NaOCl temperature variations do not significantly impact the accuracy of EALs in determining WL. These findings underscore the reliability of contemporary EALs under diverse clinical conditions, including the newly evaluated Ai-Pex. Further in vivo studies are recommended to validate these results.

Abbreviations

EAL	Electronic apex locator
NaOCl	Sodium hypochlorite
RCT	Root canal therapy
WL	Working length

AWL Actual working length
EWL Electronic working length
SD Standard deviation

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Not applicable.

Author contributions
İSCK.: writing—original draft, writing—review and editing, methodology, investigation, funding acquisition, validation, formal analysis, visualization, resources. TYY.: writing—review and editing, methodology, supervision, project administration, conceptualization.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This investigation was approved by the Ethics Committee of the Faculty of Dentistry at Istanbul University (2024/60) and was conducted in accordance with the Declaration of Helsinki ethical principles. Informed consent to participate was obtained from all of the participants in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Sjögren U, Figdor D, Persson S, Sundqvist G. Influence of infection at the time of root filling on the outcome of endodontic treatment of teeth with apical periodontitis. Int Endod J. 1997;30(5):297–306.
2. AAE. Glossary of endodontics terms. 10th ed. Chicago: American Association of Endodontists; 2020.
3. Gordon MPJ, Chandler NP. Electronic apex locators. Int Endod J. 2004;37:425–37.
4. McDonald NJ. The electronic determination of working length. Dent Clin North Am. 1992;36:293–307.
5. Martins JN, Marques D, Mata A, Caramês J. Clinical efficacy of electronic apex locators: systematic review. J Endod. 2014;40:759–77.
6. De-Deus G, Cozer V, Souza EM, Silva EJNL, Wigler R, Belladonna FG, et al. Micro-CT study of the in vivo accuracy of a wireless electronic apex locator. J Endod. 2022;48(9):1152–60.
7. Kobayashi C, Suda H. New electronic Canal measuring device based on the ratio method. J Endod. 1994;20:111–4.
8. Kobayashi C. Electronic Canal length measurement. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1995;79:226–31.
9. Ali R, Okechukwu NC, Brunton P, Nattress B. An overview of electronic apex locators: part 2. Br Dent J. 2013;214:227–31.
10. Piasecki L, Dos Reis PJ, Jussiani EI, Andrello AC. A micro-computed tomographic evaluation of the accuracy of 3 electronic apex locators in curved canals of mandibular molars. J Endod. 2018;44(12):1872–7.
11. De-Deus G, Cozer V, Souza EM, Silva EJNL, Belladonna FG, Simões-Carvalho M, et al. Clinical accuracy and precision of 3 multifrequency electronic apex locators assessed through micro-computed tomographic imaging. J Endod. 2023;49(5):487–95.
12. Oncu A, Sisko E, Demirel A, Celikten B. The evaluation of the accuracy of a wireless electronic apex locator in primary molar teeth. BMC Oral Health. 2024;24(1):1–8.
13. Aguiar BA, Reinaldo RS, Frota LM, Vale'de MS, de Vasconcelos BC. Root ZX electronic foramen locator: an ex vivo study of its three models' precision and reproducibility. Int J Dent. 2017;2017:5893790.
14. Marigo L, Gervasi GL, Somma F, Squeo G, Castagnola R. Comparison of two electronic apex locators on human cadavers. Clin Oral Investig. 2016;20(7):1547–50.
15. Guilin Woodpecker Medical Instrument Co. Ltd. Ai-Pex apex locator user manual. Guilin (China): Woodpecker Medical; 2023.
16. de Almeida Gardelin V, Vinholes JIAM, Grazziotin-Soares R, Pappen FG, Barletta FB. Influence of rotary and reciprocating kinematics on the accuracy of an integrated apex locator. Aust Endod J. 2023;49:202–8.
17. Abdelsalam N, Hashem N. Impact of apical patency on accuracy of electronic apex locators: in vitro study. J Endod. 2020;46(4):509–14.
18. Koç S, Kuştarcı A, Er K. Accuracy of different electronic apex locators in determination of minimum root perforation diameter. Aust Endod J.
19. Jha P, Nikhil V, Raj S, Ravinder R, Mishra P. Accuracy of electronic apex locator in the presence of different irrigating solutions. Endodontology. 2021;33(4):232–6.
20. Diemer F, Plews E, Georgelin-Gurgel M, Mishra L, Kim HC. Effect of sodium hypochlorite concentration on electronic apex locator reliability. Materials. 2022;15(3):863.
21. Ebrahim AK, Yoshioka T, Kobayashi C, Suda H. The effects of file size, sodium hypochlorite and blood on the accuracy of root ZX apex locator in enlarged root canals: an in vitro study. Aust Dent J. 2006;51(2):153–7.
22. Zehnder M. Root Canal irrigants. J Endod. 2006;32:389–98.
23. Cimpean SI, Chisnoiu RM, Colceriu Burtea AL, Rotaru R, Bud MG, Delean AG, et al. In vitro evaluation of the accuracy of three electronic apex locators using different sodium hypochlorite concentrations. Medicina. 2023;59(5):918.
24. Barakat RM, Almohareb RA, Alsuwaidan M, Faqehi E, Alaidarous E, Algahtani FN. Effect of sodium hypochlorite temperature and concentration on the fracture resistance of root dentin. BMC Oral Health. 2024;24(1):233.
25. Pilot TF, Pitts DL. Determination of impedance changes at varying frequencies in relation to root Canal file position and irrigant. J Endod. 1997;23:719–24.
26. Stojicic S, Zivkovic S, Qian W, Zhang H, Haapasalo M. Tissue dissolution by sodium hypochlorite: effect of concentration, temperature, agitation, and surfactant. J Endod. 2010;36:1558–62.
27. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: a vital-microscopic study in the rabbit. J Prosthet Dent. 1983;50:101–7.
28. De Santis R, Iaculli F, Lodato V, Gallicchio V, Simeone M, Spagnuolo G, et al. The efficacy of selected sodium hypochlorite heating methods for increasing and maintaining it ıntracanal temperature—an ex vivo study. Appl Sci. 2022;12(2):891.
29. Atkins P, William. Julio De Paula, and James Keeler. Atkins' physical chemistry. Oxford University Press; 2023.
30. Baruah Q, Sinha N, Singh B, Reddy PN, Baruah K, Augustine V. Comparative evaluation of accuracy of two electronic apex locators in the presence of contemporary Irrigants: an: In vitro: study. J Int Soc Prev Community Dentistry. 2018;8(4):349–53.
31. Jain S, Patni PM, Jain P, Raghuwanshi S, Pandey SH, Tripathi S et al. Comparison of dentinal tubular penetration of intracanal heated and preheated sodium hypochlorite through different agitation techniques. J Endod;49(6):686–91.
32. de Hemptinne F, Slaus G, Vandendael M, Jacquet W, De Moor RJ, Bottenberg P. In vivo intracanal temperature evolution during endodontic treatment after the injection of room temperature or preheated sodium hypochlorite. J Endod. 2015;41(7):1112–5.
33. Nagendrababu V, Murray PE, Ordinola-Zapata R, Peters OA, Rôças IN, Siqueira JR JF, et al. PRILE 2021 guidelines for reporting laboratory studies in endodontology: a consensus-based development. Int Endod J. 2021;54(9):1482–90.
34. Krithikadatta J, Gopikrishna V, Datta M. CRIS guidelines (checklist for reporting in-vitro studies): a concept note on the need for standardized guidelines for improving quality and transparency in reporting in-vitro studies in experimental dental research. J Conserv Dent. 2014;17(4):301.
35. de Camargo ÉJ, Zapata RO, Medeiros PL, Bramante CM, Bernardineli N, Garcia RB, et al. Influence of preflaring on the accuracy of length determination with four electronic apex locators. J Endod. 2009;35(9):1300–2.
36. Nekoofar MH, Ghandi MM, Hayes SJ, Dummer PMH. The fundamental operating principles of electronic root Canal length measurement devices. Int Endod J. 2006;39(8):595–609.

37. Alothmani OS, Friedlander LT, Chandler NP. Radiographic assessment of endodontic working length. Saudi Endod J. 2013;3(2):57–64.
38. Iparraguirre Nuñovero MF, Piasecki L, Segato AVK, Westphalen VPD, Silva Neto UX, Carneiro E. A laboratory study of the accuracy of three electronic apex locators: influence of embedding media and radiographic assessment of the electronic apical limit. Int Endod J. 2021;54(7):1200–6.
39. Lipski M, Trąbska-Świstelnicka M, Woźniak K, Dembowska E, Droździk A. Evaluation of alginate as a substitute for root-surrounding tissues in electronic root Canal measurements. Aust Endod J. 2013;39(3):155–8.
40. Rossi-Fedele G, Prichard JW, Steier L, de Figueiredo JA. The effect of surface tension reduction on the clinical performance of sodium hypochlorite in endodontics. Int Endod J. 2013;46(6):492–8.
41. Kim DW, Nam KC, Lee SJ. Development of a frequency-dependent-type apex locator with automatic compensation. Crit Rev Biomed Eng. 2000;28(3):473–9.
42. Uzunoglu E, Eymirli A, Uyanik MÖ, Çalt S, Nagas E. Calcium hydroxide dressing residues after different removal techniques affect the accuracy of root-ZX apex locator. Restor Dent Endod. 2015;40:44–9.
43. Sariyilmaz Ö, Sariyilmaz E, Keskin C. Comparative analysis of temperature changes with preheated and intracanal heated solutions and ultrasonic activation in immature teeth. J Endod. 2025;51(1):71–7.
44. Lee JJ, Nettey-Marbell A, Cook A, Pimenta LA, Leonard R, Ritter AV. Using extracted teeth for research: the effect of storage medium and sterilization on dentin bond strengths. J Am Dent Assoc. 2007;138(12):1599–603.
45. Peters OA, Peters CI, Basrani B. Cleaning and shaping of the root canal system. In: Pathway of the Pulp 12th ed. In: Berman LH, Hargreaves KM, editors. Cohen's Pathway of the Pulp 12th ed. St. Louis: Elsevier; 2020. pp. 236–303.
46. Piasecki L, Carneiro E, da Silva Neto UX, Westphalen VPD, Brandao CG, Gambarini G, et al. The use of micro–computed tomography to determine the accuracy of 2 electronic apex locators and anatomic variations affecting their precision. J Endod. 2016;42(8):1263–7.
47. Ferreira I, Braga AC, Pina-Vaz I. The precision of Propex Pixi with different instruments and coronal preflaring procedures. Eur Endod J. 2019;4(2):75–9.
48. Peker BU, Hepsenoglu YE, Ersahan S, Eyuboglu TF. Accuracy of working length measurement by Raypex 6: electronic apex locator versus actual measurements under stereomicroscope. Balk J Dent Med. 2022;26(1):15–21.

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