

Precision of two different electronic apex locators for working length determination across various embedding media: an in vitro assessment.

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ABSTRACT

Introduction: Electronic apex locators (EALs) are essential for precise working length determination, but their accuracy can be influenced by the electrical properties of the surrounding tissues. **Objectives:** This study aimed to evaluate the E-PEX EAL's accuracy in comparison to Root ZX II in determining working length across three various embedding mediums. **Materials and Methods:** 42 extracted human teeth with a single root were decoronated, and actual lengths (AL) were established microscopically. Specimens were randomly assigned to alginate, agar, or bovine gelatin embedding media (n = 14 per medium). Canal lengths were measured using E-PEX and Root ZX II. Data were analyzed using a Mixed-Model ANOVA with Bonferroni correction. **Results:** Both EALs demonstrated high accuracy across all media, ranging from 85.7% to 100% of readings within ± 0.5 mm of AL. There were no statistically significant differences between the devices in any medium after correction. In the bovine gelatin group, the E-PEX showed a trend toward greater deviation compared to Root ZX II (uncorrected $p = 0.042$); however, following controlling for multiple comparisons, this variation was not statistically significant ($p > 0.05$). **Conclusions:** Both the E-PEX and Root ZX II electronic apex locators provide high precision in determining working length, with most readings falling within ± 0.5 mm of the actual length across all tested embedding media. Additionally, the E-PEX performs comparably to the recognized Root ZX II in simulated clinical conditions.

Keywords: *Electronic apex locators; working length determination; embedding medium; endodontics.*

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1. INTRODUCTION

The primary cause of pulpal inflammation, that can lead to pulp necrosis and periapical lesions, is bacterial infection of the pulp ⁽¹⁾. Endodontic treatment uses appropriate chemo-mechanical procedures to remove contaminated radicular dentin in

order to enhance healing and avoid periapical periodontitis. To prevent reinfection, an appropriate coronal restoration must be placed following an acceptable root canal filling (RCF) ⁽²⁾.

Non-surgical root canal therapy (NSRCT) is recommended in several situations. The most prevalent symptoms are inflammation of the apical tissues and necrotic or diseased pulpal tissue. In order to manage endodontic infection and restore tooth function, NSRCT is a crucial step ⁽³⁾. Eliminating the biofilm that is contaminating the tissues within the root canal space (RCS) in order to disinfect it is one of the fundamental concepts of a root canal. To do this, the canal or canals are shaped, a microbial insult-reducing environment is created, and the RCS is filled with filler material to keep a disinfected condition ⁽⁴⁾.

Controlling the working length (WL) during NSRCT is critical to its success. An inaccurate WL can result in either under- or over-instrumentation, which can lead to treatment failure and complications like persistent pain, infection, or periapical tissue damage ⁽⁵⁾. WL is the distance from a coronal reference point to the point where canal preparation and obturation ought to terminate, according to the American Association of Endodontists (AAE). ⁽⁶⁾. The endodontic field has been debating and researching the precise ending of the WL for an extended period without coming to a consensus. Even though some authors recommend terminating preparation and obturation at the apical constriction, others suggest stopping at the apical foramen ⁽⁷⁾. In the context of in vitro electronic working length determination, the apical foramen is frequently chosen as the reference point for Actual Length (AL) due to its visual reproducibility under magnification, whereas the apical constriction is historically variable and difficult to locate precisely ⁽⁸⁾.

Electronic Apex Locators (EALs) were introduced to aid in the accurate determination of WL and overcome the limitations of radiographic methods. Radiographs only provide a two-dimensional representation and may suffer from errors such as image distortion or superimposition. In contrast, EALs function by measuring electrical impedance or resistance to locate the apical foramen ⁽⁹⁾.

The Root ZX II is a widely used electronic apex locator (EAL) recognized for providing accurate and reliable results. The device's dual-frequency measurement and self-calibrating technology are key to its consistent performance, even in challenging clinical conditions ^(9,10). Recently, a new device, the E-PEX electronic apex locator, has been introduced. In order to calculate canal length, the E-PEX uses automated calibration and multi-frequency impedance readings. It also has the unique feature of integration with a rotary handpiece, potentially allowing clinicians to perform canal preparation while continuously monitoring WL ⁽¹¹⁾.

These sophisticated apex locators have built-in microprocessors that can handle constant shifts in resistance information as the files go through the canal utilizing algorithm computations. This makes it possible for the apex locators to precisely ascertain a tooth's operating length. According to investigations, a contemporary electronic apex locator can determine WL with approximately 90 percent precision ⁽¹²⁾.

The embedding medium significantly influences the electrical environment in which an Electronic Apex Locator (EAL) operates. EALs work by creating an electrical circuit, and the properties of the medium surrounding the tooth in an ex vivo (lab-based) study can alter the circuit's electrical behavior, thereby affecting the accuracy of the measurement. This is because different embedding media vary in their conductivity, pH, and ion content ⁽¹³⁾.

Objectives

This in vitro investigation was conducted to assess the accuracy of the E-PEX electronic apex locator in comparison to Root ZX II across three different embedding mediums: alginate, agar, and bovine gelatin. The null hypothesis of the current research was that there would be no significant variation amongst the E-PEX and Root ZX II in assessing canal length across different embedding mediums.

2. MATERIALS AND METHODS

Preparation of Teeth:

Before the investigation started, 42 extracted single-rooted teeth were kept at ambient temperature in a 2% thymol solution. Using the dental microscope, the teeth were inspected for defects such as big canals, immature apex, and fractures. Only teeth with mature apices and root curvatures less than 25° (according to Schneider's method) were included. Teeth with open apices or root fractures were excluded. Before any procedure, teeth were immersed in 6% sodium hypochlorite (NaOCl) for a period of 10 minutes to extract external organic debris ⁽¹⁴⁾. Teeth were then assigned to one of three groups (n = 14 per group) utilizing a computer-generated randomization sequence (Random.org).

Grouping:

A total of 42 extracted single root teeth were included in the investigation. Following preparation and inspection, the teeth

were randomly assigned into three equal groups (n = 14 per group), according to the embedding medium used: Group 1: Alginate. Group 2: Agar-agar. Group 3: Bovine gelatin.

Experimental Design:

Using a diamond disk, crowns were divided at the cemento-enamel junction perpendicular to the long axis. Apical patency was established using a #10 C-file (Lexicon C-File, Johnson City TN). A 20.04 Edgefile X7 (EdgeFile® X7, Albuquerque, NM) with a stopper at 10 mm was utilized to shape the coronal portion of the canal. The canals were irrigated with 6% NaOCl. To determine the Actual Length (AL), a #15 K-file (Lexicon C-File, Johnson City TN) was introduced into the canal till its tip was tangentially visible at the major apical foramen under the DOM at 16x magnification. The #15 K-file was selected to ensure adequate tactile fit at the apical third for the selected mature teeth, ensuring electrical contact with the canal walls. Two stoppers were positioned at the occlusal referencing point to reduce measurement error. A digital caliper (Johnson Level 1889-0600, 6" Digital Caliper) with 0.01 mm accuracy was employed to gauge the length from stoppers to file tip. For each tooth, measurements were repeated three occasions and the average was taken. This procedure was performed by an operator who was blinded to the subsequent EAL readings.

Embedding Media:

To ensure the teeth remained in place throughout filing, each tooth was prepped before it was positioned in the embedding media by applying wax to the borders of the aperture in the lid. Each tooth was embedded in one of three media: alginate, 2% agar-agar, or 6% bovine skin gelatin. The embedding media were freshly prepared according to manufacturer instructions and poured into labeled containers.

Alginate: Alginate (Jeltrate Plus, Milford, DE, USA) was mixed based on the manufacturer's instructions, and 14 tubes were filled. To maximize surface contact amongst the roots and embedding medium, the container lids with attached roots were securely screwed on. At 23 °C, the alginate was left to set for 2.5 minutes.

Agar-agar: Two grams of agar-agar powder (Bacto Agar; Becton Dickinson, Sparks, MD, USA), 0.9 grams of sodium chloride, 0.095 grams of disodium hydrogen phosphate dehydrate, 0.018 grams of potassium dihydrogen phosphate (Optipur; Merck, Darmstadt, Germany), and 100 milliliters of distilled water were used to make the agar-agar solution. A homogenous suspension was created by heating the mixture to 100 °C while continuously swirling it. The 2% agar-agar solution was poured into 14 containers, the lids with the fixed roots were screwed on tightly, and the solution was allowed to cool to a gel-like consistency.

Gelatin: Six grams of gelatin (Sigma-Aldrich, St. Louis, MO, USA) were dissolved in one hundred milliliters of 0.9% saline solution to create a 6% gelatin solution. The mixture was distributed into 14 tubes after being heated to 100 °C for 15 minutes at a gradually rising pace while being constantly stirred. As the solution cooled and hardened, the lids with fixed roots were securely put on. After solidification, a small hole was created in each medium to allow placement of the lip clip and to complete the electrical circuit.

Electronic Apex Locators (EALs):

The devices tested were the E-PEX (Changzhou Eighteenth Medical Technology Co., China) and the Root ZX II (J. Morita Corp, Kyoto, Japan). Every device was attached to the lip clip and a #15 K-file. A #15 K-file was selected to ensure adequate fit at the apical third while maintaining electrical contact. Prior to measurement, canals were irrigated with 6% NaOCl. This concentration was selected to simulate a robust clinical disinfection protocol and to test the devices under conditions of high electrical conductivity. Excess irrigant was removed with paper points, leaving the canal walls moist to facilitate conduction.

Files were intentionally extended beyond the apex and then retracted until the EAL display indicated the "APEX" or "0.0" mark. The stopper position was recorded, and the file measured. Every measurement was done on three separate occasions, then the mean was considered the EAL-determined canal length. The operator recording EAL measurements was blinded to the previously established AL values. The measurements within ± 0.5 mm of AL were considered clinically acceptable⁽¹⁵⁾.

Statistical Analysis:

IBM SPSS Statistics software, version 28 (IBM Corp., Armonk, NY, USA), was used to analyze the data, and the Shapiro-Wilk test was used to confirm normality. The primary outcome was the deviation (EAL Measurement – Actual Length), where negative values indicated underestimation and positive values overestimation. The primary hypothesis test was a Two-Way Mixed-Model ANOVA evaluating the effects of embedding medium (between-subjects) and device (within-subjects), including their interaction. Secondary analyses included 95% Limits of Agreement (LoA) to assess clinical agreement, Bonferroni-adjusted pairwise comparisons, and effect size calculations (Cohen's d and Partial Eta Squared). Statistical significance was set at $p < 0.05$.

3. RESULTS

Mean Variances Amongst Actual Length and EAL Measurements:

The Two-Way Mixed-Model ANOVA revealed a non-significant main effect for the Embedding Medium ($F(2,39) = 0.87$, $p = 0.42$) and a significant main effect for the Device ($F(1,39) = 4.32$, $p = 0.042$). The interaction between Device and Embedding Medium was non-significant ($F(2,39) = 0.71$, $p = 0.49$). The mean differences between the actual length (AL) and the canal lengths determined by the E-PEX and Root ZX II across embedding media are summarized in **Table 1** and **Figure 1**.

In alginate, the E-PEX displayed a mean difference of -0.02 mm (SD = 0.29), while the Root ZX II displayed -0.01 mm (SD = 0.25). In agar, the E-PEX slightly overestimated canal length ($+0.05$ mm), whereas the Root ZX II slightly underestimated it (-0.04 mm). In gelatin, the E-PEX displayed a mean deviation of -0.03 mm (SD = 0.31), while the Root ZX II measured $+0.01$ mm (SD = 0.28). Furthermore, Post-hoc pairwise comparisons with Bonferroni correction yielded the following results for each medium (**Table 2** and **Figure 2**):

Alginate: The mean difference between E-PEX (-0.02 ± 0.29 mm) and Root ZX II (-0.01 ± 0.25 mm) was -0.01 mm (95% CI: -0.18 to 0.16). This variation was non-statistically significant ($p > 0.999$), with a negligible effect size (Cohen's $d = 0.04$).

Agar: The mean difference between devices was 0.09 mm (95% CI: -0.09 to 0.27). This difference was non-statistically significant ($p > 0.05$), and the effect size was small (Cohen's $d = 0.30$).

Gelatin: The E-PEX deviated slightly more from the Actual Length (Mean $\Delta = -0.03 \pm 0.31$ mm) compared to the Root ZX II (Mean $\Delta = +0.01 \pm 0.28$ mm). The mean variation amongst the devices was 0.04 mm. While a trend was observed in the gelatin group ($p = 0.042$ uncorrected), it did not retain statistical significance after Bonferroni adjustment ($p = 0.126$).

Table 1: Mean differences (mm) between actual length (AL) and electronic apex locator (EAL) measurements in different embedding media

Embedding Medium	Device	Mean Variation (mm) \pm SD	95% CI	p-value
Alginate	E-PEX	-0.02 ± 0.29	-0.17 to 0.13	0.78 N.S.
	Root ZX II	-0.01 ± 0.25	-0.14 to 0.12	0.89 N.S.
Agar	E-PEX	$+0.05 \pm 0.32$	-0.11 to 0.21	0.51 N.S.
	Root ZX II	-0.04 ± 0.27	-0.18 to 0.10	0.56 N.S.
Gelatin	E-PEX	-0.03 ± 0.31	-0.19 to 0.13	0.70 N.S.
	Root ZX II	$+0.01 \pm 0.28$	-0.13 to 0.15	0.91 N.S.

N.S = not significant ($p > 0.05$). P-values represent a one-sample t-test comparing the mean difference against zero (ideal accuracy).

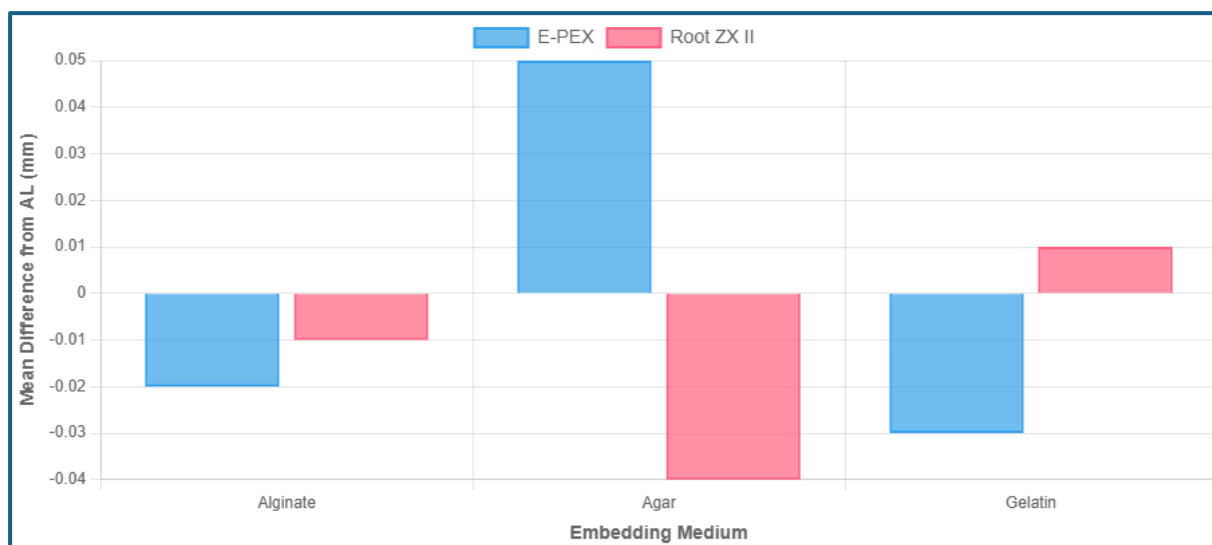


Figure 1: Mean Differences Between Actual Length and EAL Measurements

Table 2: Pairwise comparison between E-PEX and Root ZX II across embedding media

Embedding Medium	Mean Difference (E-PEX - Root ZX II)	95% CI	p-value (uncorrected)	p-value (Bonferroni)	Cohen's d	Effect Size
Alginate	-0.01 mm	-0.18 to 0.16	0.78	>0.999	0.04	Negligible
Agar	0.09 mm	-0.09 to 0.27	0.54	>0.05	0.30	Small
Gelatin	0.04 mm	-0.14 to 0.22	0.042*	0.126 N.S.	0.13	Small

* Significant before Bonferroni correction but not after adjustment ($\alpha = 0.05/3 = 0.017$). N.S. = not significant ($p > 0.05$).

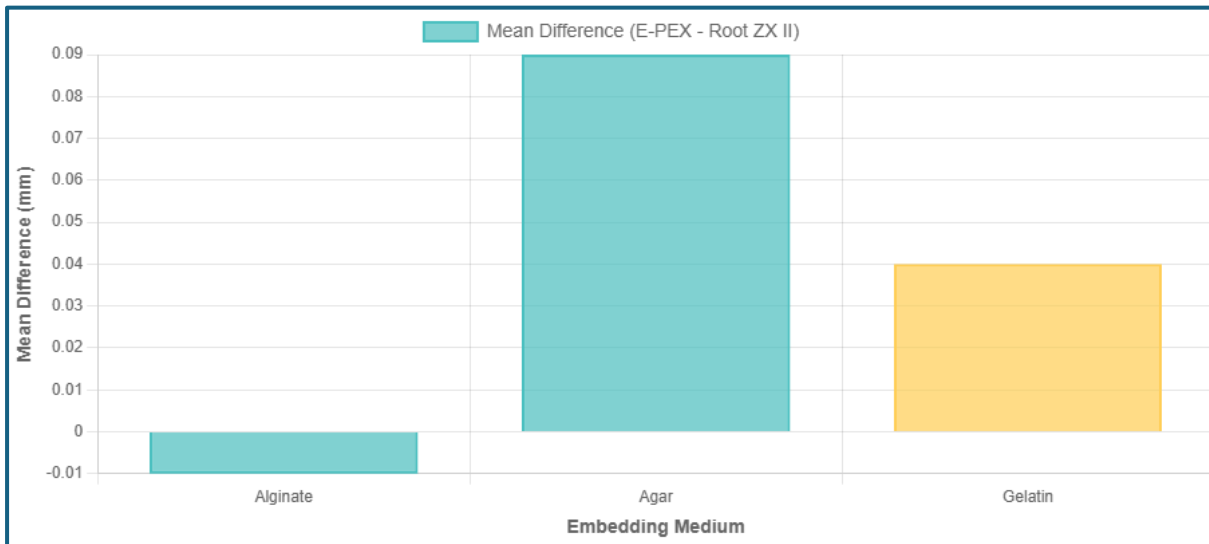


Figure 2: Pairwise Device Comparison (Mean Difference: E-PEX - Root ZX II)

Limits of Agreement (LoA):

To further characterize the agreement between the EAL readings and the Actual Length, 95% Limits of Agreement (LoA) were calculated.

Alginate: E-PEX (LoA: -0.59 to +0.55 mm) vs. Root ZX II (LoA: -0.50 to +0.48 mm).

Agar: E-PEX (LoA: -0.58 to +0.68 mm) vs. Root ZX II (LoA: -0.57 to +0.49 mm).

Gelatin: E-PEX (LoA: -0.64 to +0.58 mm) vs. Root ZX II (LoA: -0.54 to +0.56 mm).

Additionally, Root ZX II demonstrated slightly narrower limits of agreement across all media, indicating consistent reproducibility, although the overlap with E-PEX intervals was substantial.

Accuracy Within ±0.5 mm of Actual Length:

Both devices demonstrated high precision, with accuracy rates exceeding 85% across all groups. The proportion of measurements within ±0.5 mm of AL is presented in **Table 3 and Figure 3**. McNemar's test displayed non-statistically significant variations in the proportion of accurate measurements among the E-PEX and Root ZX II for any embedding medium ($p > 0.05$).

Alginate: Root ZX II achieved 100% accuracy, while E-PEX achieved 92.9% (95% CI: 66.1–99.8%).

Agar: Root ZX II achieved 92.9%, while E-PEX achieved 85.7% (95% CI: 57.2–98.2%).

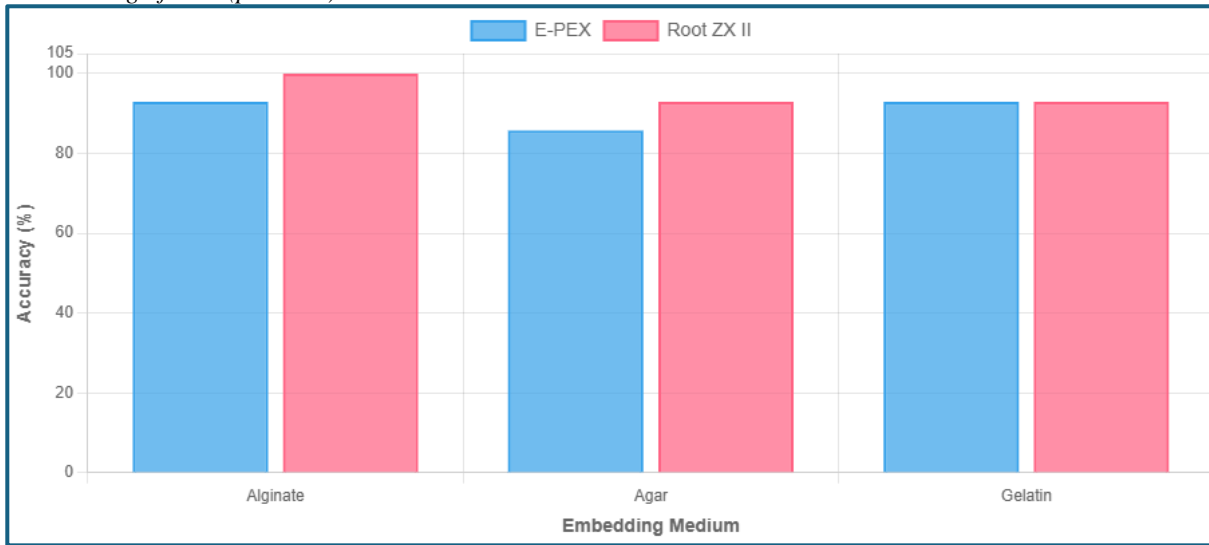
Gelatin: Both devices achieved 92.9% accuracy (95% CI: 66.1–99.8%).

Table 3: The percentage of measurements that were within ±0.5 mm of the actual length (AL)

Embedding Medium	Device	% within ±0.5 mm	95% CI	McNemar's p-value
Alginate	E-PEX	92.9%	66.1–99.8%	0.32 N.S.
	Root ZX II	100%	76.8–100%	
Agar	E-PEX	85.7%	57.2–98.2%	0.56 N.S.
	Root ZX II	92.9%	66.1–99.8%	
Gelatin	E-PEX	92.9%	66.1–99.8%	0.78 N.S.

Embedding Medium	Device	% within ± 0.5 mm	95% CI	McNemar's p-value
	Root ZX II	92.9%	66.1–99.8%	

N.S = not significant ($p > 0.05$).



Figure

3: Accuracy Within ± 0.5 mm of Actual Length

Influence of Embedding Medium:

Two-Way Mixed-Model ANOVA results are presented in **Table 4 and Figure 4**. The analysis showed that embedding medium did not exert a significant main effect on accuracy ($F(2,39) = 0.87, p = 0.42, \text{partial } \eta^2 = 0.043$). However, a significant device effect was noted ($F(1,39) = 4.32, p = 0.042, \text{partial } \eta^2 = 0.100$), suggesting a general variation in performance between E-PEX and Root ZX II, although specific pairwise differences did not retain statistical significance after Bonferroni correction. No significant medium \times device interaction was observed ($F(2,39) = 0.71, p = 0.49, \text{partial } \eta^2 = 0.035$), indicating that the relationship between the two devices remained consistent across different embedding media.

Table 4: Two-Way Mixed-Model ANOVA results

Source of Variation	df	F-value	p-value	Partial η^2	Interpretation
Embedding Medium	2	0.87	0.42 N.S.	0.043	Small effect
Device	1	4.32	0.042*	0.100	Medium effect
Medium \times Device	2	0.71	0.49 N.S.	0.035	Small effect
Error	39	-	-	-	-

N.S = not significant ($p > 0.05$). * Significant at $\alpha = 0.05$.

Partial η^2 interpretation: 0.01 = small, 0.06 = medium, 0.14 = large effect.

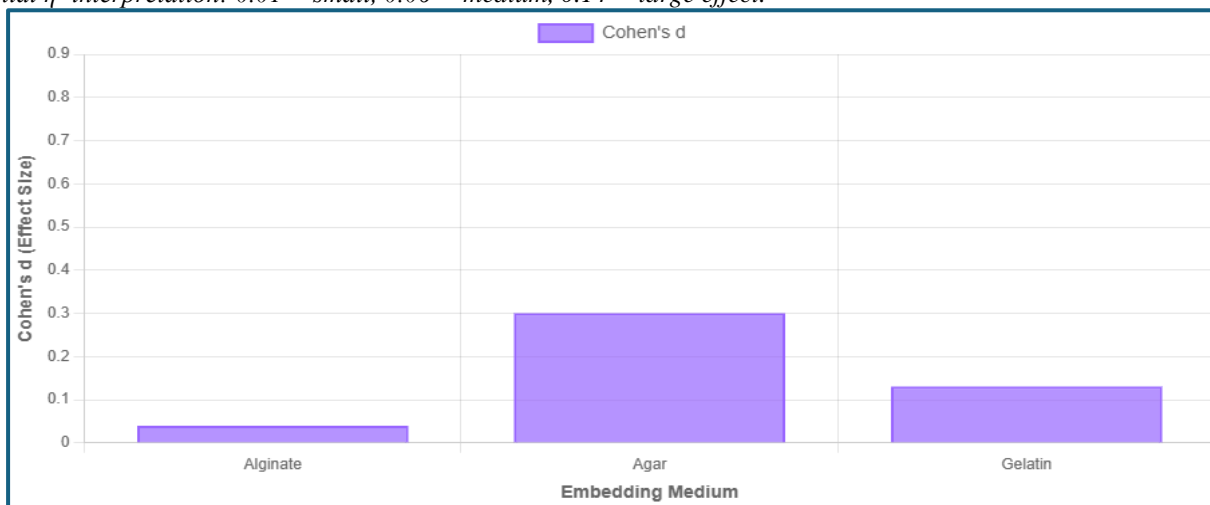


Figure 4: Effect Sizes (Cohen's d) for Device Comparisons

4. DISCUSSION

An accurate working length (WL) is foundational to a successful root canal treatment because it establishes the precise apical endpoint for cleaning, shaping, and filling the canal. The integrity of the periapical tissue is maintained by ensuring that instruments and materials do not extend beyond the root canal system⁽¹⁶⁾. Electronic apex locators (EALs) are utilized in endodontics to determine the length of a tooth's root canal with high precision. Unlike traditional radiography, EALs measure the change in electrical impedance between a file inside the canal and an electrode on the patient's lip⁽¹⁵⁾.

Root ZX II was selected as a benchmark device due to its long-standing reputation as a "gold standard" in endodontics. Its dual-frequency measurement and self-calibrating technology contribute to its consistent performance⁽¹⁷⁾. The E-PEX electronic apex locator was chosen as a newer, contemporary device for comparison. In the present study, it was found that its accuracy was comparable to the established Root ZX II. By comparing a newer device against a well-validated one, this study aimed to assess E-PEX's performance relative to a recognized standard⁽¹⁸⁾.

The type of embedding medium can influence the electrical environment in which an EAL operates, as each medium differs in conductivity, pH, and ion content⁽¹³⁾. Alginate is a widely accepted embedding medium in ex vivo EAL studies due to its ease of handling, acceptable conductivity, and ability to mimic the periodontal ligament's electrical properties⁽¹⁹⁾. Agar is also considered a suitable embedding material, providing electrical resistance that closely approximates periodontal ligament tissue and exhibiting minimal shrinkage after gelation, thus offering a more stable environment for repeated measurements⁽²⁰⁾.

Bovine gelatin was specifically included to investigate the EALs' performance in a medium with potentially different electrical characteristics. Gelatin is a protein-based polymer derived from collagen, and its electrical properties, such as conductivity, pH, and ionic concentration, can differ significantly from alginate and agar⁽¹³⁾. This difference in electrical properties can affect the accuracy of EAL measurements, with some research suggesting that gelatin models can lead to longer or erroneous electronic readings compared to alginate or saline⁽¹³⁾. Therefore, its inclusion allowed for a comprehensive evaluation of how variations in the surrounding medium's electrical properties impact EAL precision.

This study demonstrated that the electronic apex locators (EALs) Root ZX II and E-PEX measured canal lengths very close to the visual actual length (AL), with most readings falling within the clinically accepted tolerance of ± 0.5 mm of the actual length^(19,20). This range is widely considered clinically acceptable for working length determination, as it is often difficult to achieve with other methods in clinical practice⁽²¹⁾. Many studies report accuracy rates exceeding 80-90% within this ± 0.5 mm margin for various modern EALs, reinforcing the reliability of these devices in contemporary endodontic practice^(11,21). Similarly, Saxena et al.⁽²²⁾, reported accuracy rates between 80% and 90% for three different EALs (iRoot, iPex II, and Propex Pixi) when compared against histological sections, further validating the high precision of electronic length determination.

These results are consistent with systematic review that confirm the high precision of contemporary frequency-based EALs in determining working length (WL) within clinically acceptable ranges⁽¹⁵⁾. Additionally, previous study conducted by Chaudhary et al.⁽²³⁾ validated the accuracy of Root ZX and its successors, supporting the reliability of Root ZX II observed in this study.

The use of 6% sodium hypochlorite (NaOCl) in this study is a relevant factor. Although irrigants were not varied, their influence on EAL readings is well documented. High concentrations of NaOCl are known to significantly increase dentin permeability and electrical conductivity⁽²⁴⁾. While this challenges EALs by creating a highly conductive environment, both devices maintained high accuracy in this study. This suggests that modern multi-frequency algorithms are capable of compensating for the strong ionic currents generated by 6% NaOCl, validating their use in aggressive irrigation protocols. This is in line with research by Saxena et al.⁽²²⁾, who utilized 2.5% NaOCl irrigation and observed that the presence of the irrigant did not compromise the accuracy of the tested EALs. These findings parallel the medium-related variations observed in this study, highlighting the importance of the electrical environment on EAL performance.

The findings of present study found nonsignificant variations between devices across alginate, agar, or bovine gelatin models after correcting for multiple comparisons. Although the Mixed-Model ANOVA indicated a statistically significant main effect for the "Device" factor ($p = 0.042$), the clinical relevance of this signal is limited. The absolute mean differences between devices ranged from only 0.01 mm to 0.09 mm, which is clinically negligible. Furthermore, pairwise comparisons did not retain significance after Bonferroni correction. This supports the conclusion that the E-PEX performs comparably to the recognized Root ZX II for clinical working length determination. A recent clinical investigation reported similar accuracy across E-PEX and Root ZX II in vital teeth, confirming the findings of the present in vitro study⁽²⁵⁾. Alginate and agar are known for their good electrical conductivity, which closely mimics the impedance values of human periodontal tissues^(17,27). These properties may explain the stable performance of both devices in these media.

After adjusting for multiple comparisons, the bovine gelatin group did not show a significant variation, although an initial trend toward deviation was noted (uncorrected $p = 0.042$). Wolf et al. ⁽²⁰⁾ noted that alginate, agar, and gelatin differ in electrical properties, such as resistance and pH, which can slightly influence EAL measurements. The slight variation observed with gelatin may be explained by its lower ionic concentration and altered conductivity compared with alginate and agar ⁽¹³⁾. Although not statistically significant in this study, the trend suggests that newer devices like the E-PEX might exhibit slight variability in response to differences in impedance profiles, whereas the Root ZX II has been noted for its relative insensitivity to variations in medium conductivity ⁽¹³⁾.

The observed difference with gelatin may be explained by its lower ionic concentration and altered conductivity compared with alginate and agar ⁽¹³⁾. Chen et al. ⁽²⁷⁾, reported that the utilization of alginate as embedding media demonstrated a higher accuracy tendency than gelatin. Agar is a polysaccharide derived from seaweed, while gelatin is a protein-based polymer derived from collagen. These compositional differences create variations in their electrical properties ⁽²⁸⁾. Ionic concentration is a primary contributor to a solution's conductivity. Agar has no nutritional value and is chemically stable, meaning it does not readily release ions. Gelatin, conversely, is composed of complex protein chains with charged groups and interacts with added ions, which can change its concentration and conductivity ⁽²⁹⁾.

The null hypothesis, which stated that when assessing canal length across various embedding mediums, there would be no discernible variation across the E-PEX and Root ZX II, was accepted. No significant variations were observed across the devices in alginate, agar, or bovine gelatin models after statistical correction.

The study had several limitations. The in vitro design used embedding media that only partially replicated the electrical properties of periodontal tissues. It fails to account for the full biological complexity of an in vivo environment. Future research should replicate these findings in vivo across a larger variety of clinical situations (vital vs necrotic pulps, different irrigant regimes), investigate the specific electrical response profiles of E-PEX vs Root ZX II under varied ionic conditions.

5. CONCLUSIONS

This in vitro study demonstrated that E-PEX and Root ZX II electronic apex locators provide high precision in determining working length, with most readings falling within ± 0.5 mm of the actual length across all tested embedding media. Additionally, the E-PEX performs comparably to the recognized Root ZX II in simulated clinical conditions.

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