Original Article

Comparative evaluation of efficacy in working length determination: Radiography versus Electronic apex locators using *in vivo* and *ex vivo* methods with stereomicroscope validation

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Abstract

Background: Accurate determination of the working length (WL) is crucial for successful endodontic treatment. Various methods, including radiography and electronic apex locators (EALs), are employed for WL measurement, each with its advantages and limitations.

Aim: This study aimed to compare the accuracy of WL determination using conventional radiography and the Root ZX Mini EAL against an *ex vivo* gold standard method.

Materials and Methods: Fifty single-rooted teeth scheduled for extraction were included. WLs were determined using radiography (Grossman's method) and the Root ZX Mini EAL. An *ex vivo* method served as the gold standard with WL carried out on extracted teeth under a stereomicroscope. Statistical analysis included Paired samples *t*-test, Chi-square test, and Bland–Altman plots.

Results: The mean WL values were comparable among methods, with slight variations in precision. The Root ZX Mini EAL demonstrated significantly lower mean absolute error compared to radiography ($P < 0.001$). Accuracy within ± 0.5 mm and ± 1 mm tolerance ranges favored the EAL over radiography ($P = 0.04$ and $P = 0.004$, respectively).

Conclusion: The Root ZX Mini EAL exhibited superior accuracy and lower error rates in WL determination compared to radiography. Integrating EALs alongside radiographic techniques is recommended to optimize WL precision in clinical practice.

Keywords: Electronic apex locator; radiography; stereomicroscope; working length determination

INTRODUCTION

Achieving successful endodontic treatment hinges on the meticulous execution of biomechanical preparation of the root canal disinfection, and obturation, with precise determination of the canal length being crucial.[1] This measurement directly impacts the working length (WL), which is essential for the success of the therapy.

Accurate determination of the WL of a tooth is crucial for endodontic treatment success. Failure to do so can lead to incomplete cleaning, underfilling, and persistent bacterial presence, potentially causing periradicular lesions. Kuttler (1955) identified the narrowest canal diameter within the dentin, termed the minor diameter, where most experts prefer to end canal preparation.[1]

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Date of submission : 18.06.2024
Review completed : 20.06.2024
Date of acceptance : 21.06.2024
Published : 07.08.2024

Access this article online

Quick Response Code:

Website: https://journals.lww.com/jcde

DOI: 10.4103/JCDE.JCDE_381_24

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How to cite this article: Saha D, Mazumdar D, Biswas M, Chanani A, Das S. Comparative evaluation of efficacy in working length determination: Radiography versus Electronic apex locators using *in vivo* and *ex vivo* methods with stereomicroscope validation. J Conserv Dent Endod 2024;27:790-4.

Previous research emphasizes the importance of precise WL determination for effective biomechanical preparation and obturation, significantly impacting treatment outcomes.[2] Electronic apex locators (EALs) have advanced, using multiple frequencies to measure canal impedance for accurate WL determination. Despite their advantages, radiographs remain popular. Various studies have compared WL determination methods with mixed results.[1,3-5] This study compares the accuracy of WL determination using the Root ZX Mini apex locator and radiographic methods.

MATERIALS AND METHODS

This study compared WL determination by two *in vivo* methods: conventional radiography and EAL against an *ex vivo* method considered the gold standard. After obtaining approval from the institutional ethics committee, the study involved consenting adult patients with single-rooted teeth indicated for extraction due to hopeless periodontal prognosis or prosthodontic reasons. Exclusion criteria for the study included teeth with resorption, immature apices, extremely narrow, constricted, calcified, or obliterated canals, severe root curvature, multiple roots, previous endodontic treatment, or those that had undergone apical resection. A minimum sample size of 50 subjects was determined using G*Power Software (version 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany), calculated for a repeated measures analysis of variance model with an effect size of 0.2, alpha error of 0.05, 80% power, and a two-tailed significance level (α) of 0.05, based on prior research. For all participants, a preoperative periapical radiograph (X mind, Satelec, France) was taken using the paralleling technique. A single operator with clinical experience in the specialty for 10 years carried out the measurements.

Local anesthesia was administered, and the tooth was isolated with a rubber dam. An endodontic access cavity was created for each tooth using a long-shank diamond round bur in a high-speed handpiece, followed by routine canal extirpation.

Working length determination

Conventional radiograph

In vivo, radiography was employed to establish a tentative WL using a preoperative radiograph. A K-file (Mani Inc., Japan) and Endo gauge (Dentsply Maillefer, Ballaigues, Switzerland) aided in this process, with the K-file positioned 1 mm short of the tentative WL. Subsequently, an intraoral periapical radiograph was taken using the paralleling technique, utilizing parameters of 70 kV, 7 mA, and 220 ms for radiation exposure [Figure 1a]. The WL was determined using the Grossman formula. This methodology was consistently applied across all teeth included in the study.

Electronic apex locator

To establish the WL using the Root ZX mini (J Morita Corp., Kyoto, Japan), a lip clip was affixed to the patient's lip, and the electrode was connected to a #15 K file with a silicone stopper [Figure 1b (i) and (ii)]. The file was advanced until warning signals indicated penetration of the foramen, then retracted to elicit an intermittent beep sound. On the display, the "00" symbol and a small triangle adjacent to the Flash Bar at the 0.5 marking began flashing, indicating the file tip was at or near the minor constriction. Subsequently, the file was withdrawn, and the length was measured using an endo gauge.

Ex vivo determination on extracted tooth

After electronic root canal measurement and extraction, the tooth was immersed in 5.25% sodium hypochlorite for 10 min to clean the apical root area of any periodontal tissue remnants, followed by rinsing with water. Using a stereomicroscope (Wild Makroskop M420, Heerbrugg, Switzerland) and monitor, a #15 K-file was positioned just visible at the apical foramen [Figure 1c]. After setting the silicone stop, the distance from the file tip was measured and reduced by 0.5 mm to determine the actual WL.

Statistical analysis

Data were tabulated into Microsoft Excel 2021 and analyzed using GraphPad Prism 10.1.2 Normality checks included Shapiro–Wilk's test, histograms, Q-Q plots, and box plots, indicating approximate normal distribution. Parametric tests included paired samples *t*-tests for comparing the mean absolute error between the two study methods relative to the actual WL. The Chi-square test was conducted to assess the variation in accuracy using tolerances of 0.5 mm and 1 mm. The Bland–Altman plot was drawn to visualize the agreement between the gold standard and the two methods of measuring the WL, respectively, with significance set at $P \leq 0.05$.

RESULTS

The methods were compared based on mean and standard deviation values of WL: The gold standard showed a mean of 20.71 ± 2.12 mm; the conventional radiography demonstrated a mean of 20.57 ± 2.19 mm; and Root ZX Mini EAL exhibited a mean of 20.72 ± 2.12 mm. The mean error in WL determination was − 0.14 for radiography and 0.01 for the Root ZX Mini apex locator, indicating less error with the latter, however, the difference was statistically significant ($P = 0.258$). The mean absolute error of WL was significantly lower ($P < 0.001$) in the Root ZX Mini locator (0.25 ± 0.4) technique as compared to the radiography (0.72 ± 0.59) [Figure 2a]. Table 1 depicts the mean values of WL, a difference of WL from the actual measurement, and the mean absolute error for the methods used in the study.

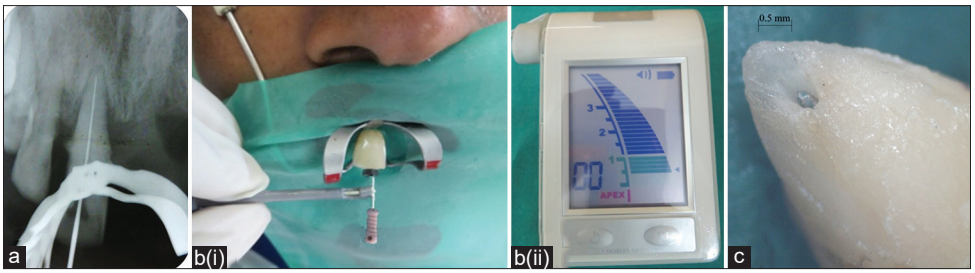

Figure 1: Methods used in the study to determine the working length (WL): (a) Conventional radiograph, (b) (i) Measurement by electronic apex locator, (ii) Root ZX Mini Apex Locator, and (c) Visualization under a stereomicroscope for actual WL

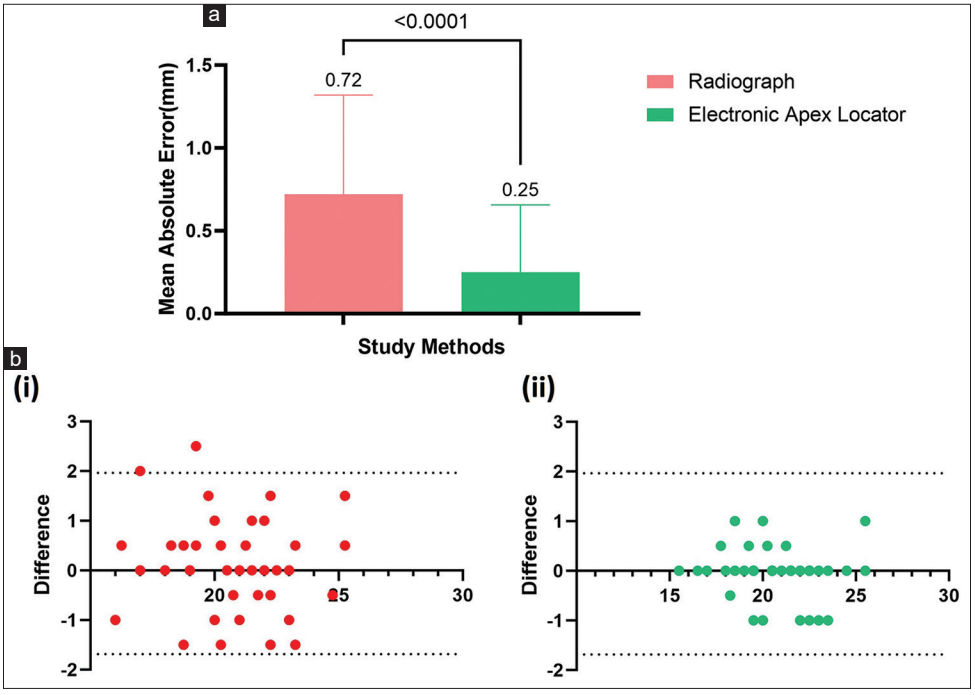

Figure 2: Graphical representation of data: (a) Bar graph showing the mean absolute error for the working length determined by the electronic apex locator (EAL) and the radiographic method, respectively about the gold standard method with significant comparisons. (b) Bland–Altman Plots of (i) Radiographic method and (ii) EAL. Note: Upper Dotted lines: Upper 95% limits of agreement; Middle line with ticks: Mean; Lower Dotted lines: Lower 95% limits of agreement

Table 1: Mean working length, difference of working length from the actual measurement, and the mean absolute error for electronic apex locator and radiographic technique

Methods/parameters	WL (mm)	Difference from actual (mm)	Absolute error (mm)
Actual (under stereomicroscope)	20.71±2.12	-	-
EAL	20.72±2.12	0.01	0.25±0.4*
Radiograph	20.57±2.19	−0.14	0.72±0.59

*Mean absolute error for Root ZX Mini EAL was significantly lesser than the radiograph. WL: Working length, EAL: Electronic apex locator

When the accuracy was assessed in relation to the measurements under a stereomicroscope [Table 2], 80% (n = 40) of cases using an EAL achieved precise measurements, compared to 58% (n = 29) with radiography, within the tolerance range of ± 0.5 mm, with a statistically significant association, implying a significantly higher accuracy of the former (P = 0.04).

Within the tolerance range of ± 1 mm, all the cases (100%, n = 50) showed an accurate reading in the case of EAL, which was significantly higher than the accuracy of the radiographic technique (80%, n = 40) (P = 0.004).

The Bland–Altman plot suggested with radiographs, the plot exhibits a wider range of differences (-1.69-1.9) compared to the plot for EAL (-0.98-0.88). In addition, the EAL Plot demonstrates better agreement, with more data points clustered tightly around the mean difference line and fewer outliers, whereas the plot for the radiograph has more points outside the limits of agreement, indicating greater instances of significant differences between the methods [Figure 2b (i) and (ii)].

Table 2: Comparison of the distribution of the observations, evaluating the accuracy of each method within a±0.5 mm and±1 mm range, respectively

Tolerance	±0.5 mm			±1 mm		
Methods/levels	Accurate	Overestimation	Underestimation	Accurate	Overestimation	Underestimation
EAL	40 (80)	4 (8)	6 (12)	50 (100)	-	-
Radiograph	29 (58)	11 (22)	10 (20)	40 (80)	5 (10)	5 (10)

All values are expressed in terms of frequencies (%). EAL: Electronic apex locator

DISCUSSION

A critical aspect of endodontic treatment is accurately determining and preserving the biological length of the root canal system. According to prognostic studies, proper treatment termination at the apical constriction supports optimal healing and influences treatment success.[6] In the present study, we compared the accuracy of conventional radiographic techniques using Grossman's formula and EAL to determine WL. Root ZX Mini apex locator was chosen for its self-calibration capability and enhanced microprocessor technology. Its operation is based on detecting changes in electrical capacitance at the apical constriction. Previous studies, including those by Shabahang *et al.*[7] and Pagavino *et al.*,[8] have confirmed its accuracy and reliability in various canal conditions and clinical settings.

In the present study, out of 50 cases, Root ZX Mini EAL gave reading beyond the actual WL in four cases (8%), while six cases (12%) exhibited underextension in WL determination. However, the Root ZX mini apex locator in this study demonstrated 100% accuracy in determining the apical constriction within the ± 1 mm tolerance range [Table 2]. These findings align with Tselnik *et al.*,[9] Haffner *et al.*,[10] and Wrbas *et al.*,[11] who reported 75% and 78% accuracy, respectively, within ± 0.5 mm. Goldberg *et al.*[12] also found Root ZX to be 100% accurate within ± 1 mm of the apical constriction. Dunlap *et al.*[13] reported 82% accuracy within ± 0.5 mm using similar apex locator signal criteria as employed in this study. Nonetheless, the accuracy of Root ZX in this study was lower compared to the findings by Shabahang *et al.*,[7] D'Assunção *et al.*[14] and Sakkir *et al.*[15] Variations in methodologies used to measure the WL across the aforementioned studies may account for the discrepancies in results. In the present study in 20% ($n = 10$) cases, the WL did not fall within the acceptable tolerance range of ± 0.5 mm from the apical constriction. This raises the question of whether the WL should be determined at the minor constriction point indicated by the EAL or at another location.

In this study, radiographs showed 58% ($n = 29$) accuracy in determining WL within ± 0.5 mm of the apical constriction. Comparatively, radiography achieved 80% ($n = 40$) accuracy within ± 1 mm. These findings align with ElAyouti *et al.*,[16] Cianconi *et al.*,[17] and Mancini *et al.*[18] However, they differ from Ravanshad *et al.*,[19] who reported 82.1% accuracy using a bisecting angle technique. The discrepancy may be due to varying criteria: Bisecting angle versus paralleling angle and ± 0.5 mm versus 0–2 mm from the radiographic apex. Pratten and McDonald.[20] found lower accuracy (18%) in cadaver studies, possibly influenced by film speed and exposure angles. The present study demonstrated significantly lower absolute error with the Root ZX Mini apex locator compared to radiography, indicating superior accuracy in WL determination. This finding aligns with recent studies.[6,17-19] The Bland–Altman analysis confirmed these results, showing the narrowest limits of agreement and minimal bias between the EAL and the actual measurements obtained under a stereomicroscope. These findings underscore the importance of EAL in accurately determining WL.

There were two potential limitations associated with this study. One is the inclusion of only one type and one generation of EAL, which may not be representative of the variety of available EALs. Second, the accuracy of apex locator readings can be affected by periapical pathologies, such as abscesses or purulent discharge, which may distort the results. Furthermore, different endodontic irrigants may produce skewed results. Nevertheless, this study outlines a rigorous methodology used in the comparisons, offering clinically relevant and reliable data.

CONCLUSION

Based on the results of this study, it can be concluded that the Root ZX Mini is significantly more accurate, with a lower degree of error in WL determination compared to radiography. Given that neither method is 100% accurate, it is recommended that radiographic WL determination be complemented with EAL measurements to enhance accuracy and minimize errors.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

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