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Comparison of the Accuracies of CBCT, Radiography, and Four Electronic Apex Locators in Working Length Determination

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Abstract

Background: One of the significant stages during endodontic procedures is determining the correct working length (WL). This study aimed to evaluate the accuracy of four electronic apex locators (EALs) (Root ZX mini, Raypex 6, Propex Pixi, and E-Pex Pro) and cone-beam computed tomography (CBCT) and radiographic measurement in determining the actual WL (A-WL).

Methods: Thirty extracted single-root mandibular premolars were selected and flattened at the crown. The WL was determined by advancing the #15 K file until its tip was visible from the apical, and the A-WL was established by subtracting 0.5 mm from this length. The WL was also determined using periapical radiography, four EALs, and CBCT. The differences in all measurements were compared with the A-WL. The data were statistically analyzed using one-way analysis of variance (Welch) and Tamhane's test. The significance level was set at $p < 0.05$.

Results: Compared with other measurement methods, CBCT gave shorter values than the A-WL, and this finding was statistically significant compared with those of the PR and Propex Pixi groups ($p = 0.009$) ($p = 0.024$). No significant difference was observed between the other groups ($p > 0.05$) except the CBCT group ($p < 0.05$).

Conclusions: Root ZX mini and Raypex 6 made measurements close to the A-WL.

Keywords: apex locator, CBCT, periapical radiography, working length

INTRODUCTION

Appropriate root canal irrigation and shaping procedure in endodontics can only be performed after the exact working length (WL) has been calculated. Therefore, determining the correct WL, which is the distance between the coronal reference point and apical construction (AC), is one of the most critical steps in treatment.[1] The AC is the smallest diameter of the root canal and the ideal end limit for endodontic therapy. The AC is usually located 0.5–1 mm short of the apical foramen (AF).

Periapical radiography (PR) is obtained with a parallel technique with optimum contrast and gives good results in determining the WL.[2] In the radiographic technique, the actual WL (A-WL) is approximately 0.5–1 mm shorter than the radiographic length. However, PR has several disadvantages in WL determination. As radiographs give two-dimensional images of the three-dimensional structure, the superimposition of images in the buccolingual direction due to root resorptions or deviations in the location of the AF makes localization difficult.[3,4] As a result, the obtained radiographic image of the root apex may not always be clear due to distortion and magnification. A parallel technique can minimize the distortion while keeping the object as close to the film as possible to avoid magnification.[5] However, PRs show 5% elongation of the images despite the use of a parallel technique.[6] PR has limitations because of its two-dimensional nature in determining the WL. Some drawbacks, including distortion, magnification, and superimposition, may negatively affect the determination of the A-WL.[7] Cone-beam computed tomography (CBCT) images are used for several applications in endodontics, including WL determination, when the location of the major foramen is not identifiable with sufficient precision in PR.[8]

Propex Pixi (Dentsply Maillefer, Ballaigues, Switzerland), which works in dry and wet canals, has a multifrequency apex locator technology that does not require calibration and has zero adjustments.[9] Root ZX (J. Morita, Tokyo, Japan) is a third-generation apex locator that simultaneously measures and compares impedance values at frequencies of 0.4 and 0.8 kHz to detect the endpoint in the canal.[10] Root ZX mini is a device developed by the same brand, with the same features as Root ZX, only in smaller sizes.[11] The manufacturer claims that Raypex 6 (VDW, Munich, Germany) uses the latest multifrequency apex locator technology and gives precise

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results in this manner.[12] E-Pex Pro (Changzhou Eighteeth Medical Technology Co., China) is a member of the fifth generation of electronic apex locators (EALs).

The current study evaluated the degree of accuracy of CBCT, radiography, and four apex locators (Root ZX mini, Raypex 6, Propex Pixi, and E-Pex Pro) when measuring the A-WL of root canals. To the best of our knowledge, no study has compared the accuracy of these four EALs with each other in literature.

This study had two null hypotheses: (1) no difference exists between the measurement techniques and A-WL and (2) no significant difference exists between the WL determinations of EALs.

METHODS

The research protocol was approved by the Ethics Committee of Dicle University School of Dentistry (Decision No.: 2021-44). Thirty extracted single-root human mandibular premolars teeth, which were extracted for periodontal or orthodontic reasons, were included in the study. The selected teeth were stored in 0.9% saline solution. The teeth were decoronated to provide a reliable landmark for length measurement. Then, the access cavities were prepared, and the canal patency was verified with size #10 K File to the apex. NaOCl (5.25%) (Promida Co., Eskişehir, Turkey) and 30G endodontic irrigation tips (TN, Dentsply Sirona, Charlotte, NC) were used for irrigation.

A-WL determination

An investigator inserted a #15 K file with two silicone stops and advanced it until the file's tip was visible through the AF under a magnifying glass (x2.5) (Dr. Kim, Lane Cove Rd, Macquarie Park, NSW, Australia). After completion of file positioning, the silicon stoppers were adjusted for WL measurements. The distance between the file tip and silicone stopper was measured with a digital caliper that was accurate up to 0.01 mm (Mitutoyo Corp., Tokyo, Japan). Each measurement was repeated thrice, and the mean value was calculated. Finally, 0.5 mm was subtracted from the calculated measurements. Thus, the A-WL of the tooth was determined and recorded.

WL determination with CBCT [CBCT-WL]

A polyvinyl siloxane mold model (Zeta Plus, Zhermack, Badia Polesine, Italy) representing the mandibula was formed. Ten teeth were included in each model, and three models were formed. The CBCT images were obtained with I-CAT Vision™ (Imaging Science International, Hatfield, USA). Imaging parameters were set to 120 kVp, 5 mA, 8.9 s, and field of view equal to 16 × 13 cm^2 at 0.3 voxels. Images were viewed in the sagittal plane using a particular i-CAT software function that presents millimeter values. The reference distance used was the maximum width between the crown and the most apical point of the root. The measurement was 0.5 mm shorter than the root apex. All CBCT measurements were performed by an investigator well trained in CBCT diagnostic applications.

WL determination with PR [PR-WL]

Each tooth in the polyvinyl siloxane mold model was imaged one by one with the number 2 periapical film. All radiographs were obtained using an XMind unity DC X-ray device (Acteon Satalec, Germany), with settings set at 60 kVp and 7 mA, and exposed for 0.25 s, with the distance from the source to the film set at 20 cm obtained using the parallel technique. The plaques were scanned with an Acteon Sopro Pspix phosphorous plaque scanner (Acteon Satalec, Germany). The radiographic images were transferred to ImageJ (National Institutes of Health, Bethesda, MD, USA). The ImageJ program measured the tooth length by drawing a line along the canal from the flattened crown to the root tip. Then, 0.5 mm was subtracted from the tooth length and recorded as the PR-WL by an investigator.

WL determination with EAL [EAL-WL]

Teeth were removed from the polyvinyl siloxane mold model and embedded in plastic boxes containing freshly prepared alginate (Dentsply Sirona, New York, ABD) to mimic the periodontal ligament. The root canals were filled with 5.25% NaOCl. For this method, the lip clip was placed near the plastic box, and the file clip was placed in between the silicon stopper and the handle of the shaft of a 25 mm size #15K file. The lip clip was placed as far away from the box as possible to avoid interference.

- For Raypex 6, the file was advanced until the red bar appeared on the screen and withdrawn until the last yellow bar was reached. The silicone stopper was positioned at the incisal edge when this mark was reached.
- With the Root ZX mini, the file was advanced just beyond the foramen and then withdrawn until the LCD displayed "APEX."
- While measuring with the Propex Pixi device, the file was advanced until "OVER" was displayed on the screen and then withdrawn until the "00" point was reached.
- For E-Pex Pro, the file was advanced into the canal until the "00" mark lit up.

Next, the files were retrieved for measurement when the display was stable for at least 5 s, and three measurements were recorded using a digital caliper. The procedures were completed and within a period of at most 10 min to prevent alginate shrinkage. All teeth were measured by a single investigator experienced in the use of EALs. The measurements in all groups were repeated thrice, and the average was calculated.

Data calculations

The canal length measurements were made based on the study of Lucena *et al*.[13]

-The differences between CBCT-WL/PR-WL/EAL-WL measurements and A-WL were calculated.
-The differences between CBCT-WL/PR-WL/EAL-WL measurements and A-WL were classified into five categories:

- Precise: Coinciding measurements with the A-WL;
- (0) - (−0.5) mm: Including measurements within −0.5 mm of the A-WL;
- (0) - (+0.5) mm: Including measurements within +0.5 mm of the A-WL;
- (−0.5) - (−1.0) mm: Including measurements between (−0.5) - (−1.0) mm of the A-WL.
- (+0.5) - (+1.0) mm: Including measurements between (+0.5) - (+1.0) mm of the A-WL.

Statistical analysis

The Kolmogorov–Smirnov test revealed a normal distribution. The homogeneity of variances was not assumed, and the groups were compared using one-way analysis of variance (ANOVA) (Welch) and Tamhane's post hoc test. Data analysis was run using SPSS version 20 (IBM Corp, Armonk, IL), and the level of significance at 5% was accepted.

RESULTS

Table 1 and Figure 2 show the mean and standard deviation (SD) of the difference between the WL and the A-WL obtained using the EALs, PR, and CBCT. CBCT provided shorter values than the A-WL compared with those obtained by other measurement methods, and this finding was statistically significant compared with those of the PR and Propex Pixi groups (p = 0.009) (p = 0.024). No significant difference was observed between the differences obtained by subtracting the PR-WL and four EALs from the A-WL (p > 0.05).

Table 2 shows the frequency and percentages of (−1.0) - (−0.5) mm, (−0.5) - (0) mm, precise, (0) - (+0.5) mm, and (+0.5) - (+1.0) mm measurements. Raypex 6 and Root ZX Mini groups gave the most measurement at (0) - (+0.5) mm level (46.7%). Propex Pixi group gave the most measurement at (−0.5) - (0) mm level (76.7%). E-pex Pro group gave the most measurement at (−0.5) - (0) mm level (50%). CBCT and PR groups gave the most measurement at (−0.5) - (0) mm level, with values of 36.7% and 56.7%, respectively. Precise measurement was performed on one tooth in the Root ZX mini group (100%).

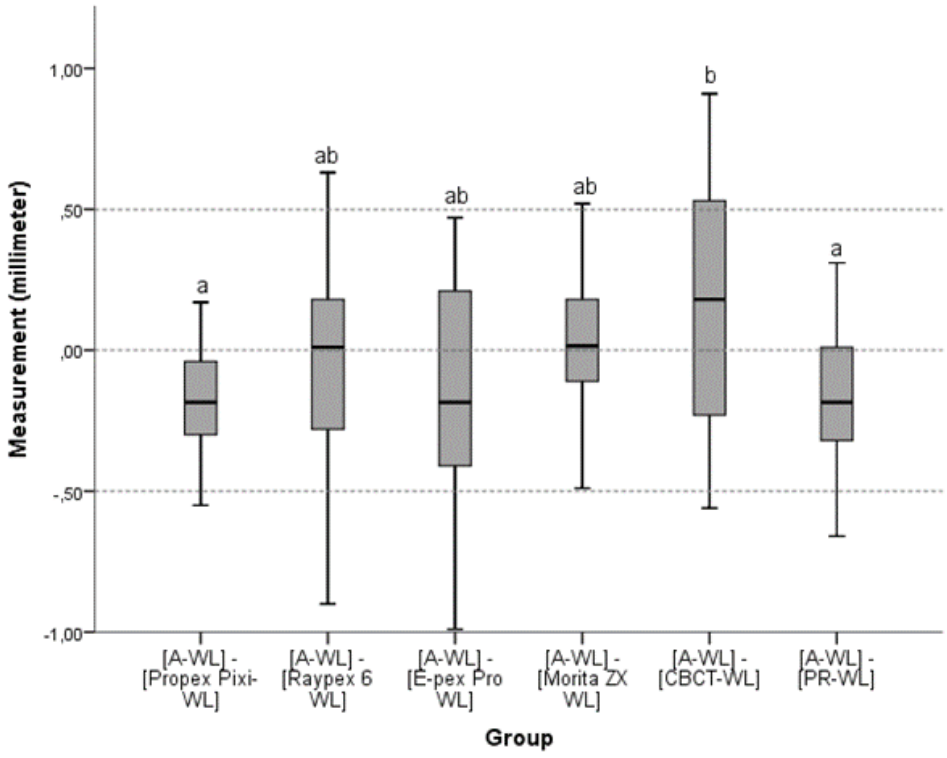

FIGURE 2. Box plot representation of the difference between the A-WL and measurements

TABLE 1. Differences between E-WL, PR-WL, and CBCT-WL measurements, and A-WL

Group (n = 30)	Mean ± SD	Minimum	Maximum
[A-WL] − [Propex Pixi-WL]	−0.15 ± 0.31	−0.95	0.59
[A-WL] − [Raypex 6 WL]	−0.03 ± 0.38	−0.90	0.63
[A-WL] − [E-pex Pro WL]	−0.13 ± 0.37	−0.99	0.47
[A-WL] − [Root ZX mini WL]	0.02 ± 0.29	−0.68	0.70
[A-WL] − [CBCT-WL]	0.18 ± 0.44	−0.56	0.91
[A-WL] − [PR-WL]	−0.18 ± 0.29	−0.88	0.59

One-way ANOVA (Welch); $p < 0.05$

TABLE 2. Distribution of differences between WL measurements by categories

Group (n = 30)	(−0.5) − (−1.0)	(0) − (-0.5)	Precise	(+0.5) − (0)	(+0.5) − (+1.0)
[A-WL] − [Propex Pixi-WL]	2	23	0	3	2
[A-WL] − [Raypex 6 WL]	4	11	0	14	1
[A-WL] − [E-pex Pro WL]	4	15	0	11	0
[A-WL] − [Root ZX mini WL]	1	13	1	14	1
[A-WL] − [CBCT-WL]	2	11	0	7	10
[A-WL] − [PR-WL]	5	17	0	7	1

DISCUSSION

The practice of estimating WL by subtracting 0.5–1 mm from the root length from the radiographic apex to the crown on periapical radiographs has been reported to be incorrect.[4] Assuming that the AC is 1 mm shorter than the radiographic apex would underestimate the WL due to the variability in the distance between the minor foramen and radiographic apex.[14] EALs have become popular due to their high accuracy in locating the AC. Their numbers have increased significantly due to the development of the latest EALs for the accurate determination of WL and have become an essential aid in endodontics.[15,16] Our study aimed to explore the accuracy of two WL assessment methods (CBCT and PR) and the measurements of four different EALs to evaluate them in comparison with the A-WL. In the present study, the first null hypothesis was not accepted because a difference was found in the accuracy of CBCT, which provided shorter values than the A-WL, compared with other measurement methods. However, Root ZX mini and Raypex 6 showed maximum accuracy compared with other EALs and PR groups, but no statistical difference was found. Therefore, the second null hypothesis was accepted. To our knowledge, no study has evaluated the accuracy of these four different EALs together.

In the present study, the A-WL group was preferred as a gold standard of the reliability, accuracy, and reproducibility of direct clinical examination of the AF.[7] Among the EALs, Root ZX mini established the WL with 90% (±0.5 mm) accuracy and one precise measurement. Our results differed from those of other studies comparing Root ZX mini.[17,18] The reason for these differences is probably related to the use of various methodologies. No significant differences were found in an in vivo study about the accuracy of Root ZX mini and Propex Pixi.[18] No significant difference was also found between these two EALs in our in vitro study. Üstün *et al*. reported that although CBCT measurement was shorter than Raypex 6 and Propex Pixi measurements, no significant differences were observed between the EALs.[19] Lucena *et al*. compared Raypex 6 and CBCT scans; the Raypex 6 was more accurate than CBCT scans in WL determination.[13] Similarly, Yılmaz *et al*. obtained shorter measurements with CBCT scans compared with EAL and A-WL.[20] Although no statistically significant difference was detected between Raypex 6 and CBCT measurements in our study, Raypex 6 was more successful than the ±0.5 mm measurement values. Although no significant difference were recoreded between EALs, Propex Pixi was more reliable than CBCT measurements. Thus, the EALs are more reliable than CBCT scans for WL determination. This study used extracted tooth and polyvinyl siloxane mold models to simulate clinical conditions for CBCT measurement. However, as the bone structures are more irregular than the silicone mold used in the model, the identification of the foramen on patient CBCT scans can be challenging.[21] In addition, the reasons for the differences between studies comparing different EALs and methods for determining WL may be the observer performance, selection of landmarks, the CBCT system used, and CBCT setting and software capabilities.

In the use of EAL, the 0.5 mark is used for locating the AC; therefore, it is recommended to be used to determine the apical border for endodontic procedures.[22,23] The presence and location of AC are highly variable and can only be evaluated by histological or microcomputed tomography.[23,24] Therefore, clinical confirmation of the

accuracy of the 0.5 mark with EALs in locating AC is impossible. However, a PR with the file is commonly obtained at the location recommended by the EALs to minimize the potential errors of electronic measurements.[25,26] In addition, many factors, such as the distance from the file tip to the apex, morphology and shape of roots, trajectory of the canal, possible bifurcation, lateral foramen, the presence of resorption, distortions, overlap, and other limitations, should be considered.[7,27] Especially in teeth that present problems for EAL measurements, such as canal obliterations or metallic crown restorations, measurement of pre-existing CBCT scans may potentially reduce or replace PRs for WL measurements.[28] Moreover, given that CBCT scans outperform intraoral radiography at all voxel sizes, CBCT data may provide additional information for endodontics rather than use pre-existing PR when determining WL in combination with EAL measurements.[28,29]

Studies indicated that canal instrument sizes do not affect the accuracy of WL determination of EALs.[30,31] However, the size of the AF, contact surface of the active electrode with the walls, and enlargement of AF diameter can cause an erroneous determination of the WL.[32] Therefore, in this study, a #15 K-file was used to determine the WL of mandibular premolars. In addition, alginate was used to mimic the periodontal ligament in the setup prepared for the measurement with EALs. Alginate dries quickly, which causes loss of electroconductivity. Therefore, some researchers recommend keeping the model moist and refrigerated until the WL determination when using alginate as a substitute for periodontal tissues.[33] Lipski *et al*. reported that measurements should be completed within 30 min after preparing the alginate.[34] In our study, we attempted to preserve the accuracy of the measurements by preparing fresh alginate in 10 min periods. The possible limitations of this study included the observation of results in a laboratory and the use of single roots and apical anatomic complexities, which may affect the performance of EALs in the clinic.

CONCLUSIONS

All four EALs used in this study are suitable for clinically acceptable measurements. Furthermore, our accuracy data suggested that these clinical devices showed the reliability of these EALs. In addition, the accuracy and reliability of CBCT were lower than those of PR and Propex Pixi when compared with EALs. More research is required to confirm the findings of this study.

CONFLICT OF INTEREST

All authors state that they have no conflict of interest.

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