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Original Article

Comparison of the accuracy of apex locator, digital radiography, and cone-beam computed tomography in root canal working length determination in teeth with external root resorption: An *in vitro* study

Seyed Mohsen Hasheminia[1], Sanaz Jahadi[2], Farida Ghazanfari Moghaddam[3], Shervin Bagherieh[4]

[1]Department of Endodontics, Dental Materials Research Center, Dental Research Institute, Isfahan University of Medical Sciences, Isfahan, [2]Department of Endodontics, Dental Implants Research Center, Dental Research Institute, Isfahan University of Medical Sciences, Isfahan, [3]Department of Oral and Maxillofacial Radiology, Dental School, Kerman University of Medical Sciences, Kerman, [4]Department of Endodontics, Dental Research Center, Dental Research Institute, Isfahan University of Medical Sciences, Isfahan, Iran

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Address for correspondence:
Dr. Farida Ghazanfari Moghaddam,
Department of Oral and Maxillofacial Radiology, Dental School, Kerman University of Medical Sciences, Kerman, Iran.
E-mail: f_gh_moghaddam@yahoo.com

ABSTRACT

Background: The aim of this study was to compare the accuracy of apex locator, digital periapical radiography, and cone-beam computed tomography (CBCT) for determining the root canal working length (WL) in teeth with external root resorption (ERR).

Materials and Methods: In this *in vitro* study, the sample consisted of 54 extracted permanent single-rooted human teeth. ERRs were performed at the 3 mm apical root using 65% of nitric acid for 24 h. After determining the actual WL by K-file #10 (gold standard) with the visualization method, the teeth were mounted in alginate and the WL of each tooth was determined using the electronic apex locator (EAL) equipped with a K-file #15. The teeth were mounted with wax in the teeth sockets of a dry human mandible, and the images were obtained by digital phosphor plate receptors and CBCT scans. The mean registered WL of each method was statistically compared with the gold standard WL using one-way ANOVA with $P < 0.001$.

Results: The mean ± standard deviation (SD) of actual WL was 16.00 ± 2.24. The mean ± SD of WLs determined by CBCT, EAL, and digital radiography were 15.38 ± 2.19, 15.52 ± 2.32, and 16.83 ± 2.20, respectively. This study showed that the mean measured WL with ERR in all methods was significantly different from the actual WL ($P < 0.001$).

Conclusion: This study showed that there was a significant difference between the actual mean WL and the EAL, digital periapical radiography, and CBCT mean WL. Thus, the combination of EAL and CBCT could be a reliable method for determining WL in the presence of ERR.

Key Words: Cone-beam computed tomography, digital radiography, endodontics, radiographic image enhancement, root resorption

INTRODUCTION

For having a successful root canal treatment with a better prognosis, determining the correct working length (WL) and diagnosis of the root resorption are necessary. The apical construction of the tooth is the most appropriate landmark for determining the correct WL in endodontic treatment; however,

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this landmark can be destructed in cases of radicular changes.[1] Some radicular changes are challenging for clinicians to diagnose, such as root perforations and external root resorption (ERR). Pulpal inflammation, orthodontic movement, trauma, jaw tumors, internal bleaching, and ectopic eruption of teeth can cause ERR in permanent dentition.[2,3]

Several devices have been developed to find the most appropriate WL for the instrumentation and obturation of root canals. The intraoral periapical radiograph is the most common tool for determining the WL, but due to different horizontal and vertical angulations, it causes distortion, magnification, and superimposition of structures which can affect the linear measurements.[4,5] Electronic apex locators (EALs) are useful in determining the WL of root canal with accuracy ranging from 55% to 93%.[6] The presence of apical anatomical complexities can impair the accuracy of WL determination by the EALs.[3] Most endodontics prefer a combination of EAL and radiographic methods to determine the WL.[7] Moreover, radiographic examination and cone-beam computed tomography (CBCT) are indispensable for the diagnosis of root resorption.[8]

CBCT is a competent tool capable of displaying additional canals, canal angulations, and apical foramen positions which are not fully detectable on intraoral radiographs.[9] CBCT is a valuable diagnostic method in root resorption cases, as it allows the determination of the size and severity of the root resorption.[10] This imaging method can provide multiplanar images of different aspects of root canal morphology. However, the radiation dose of CBCT is much higher than intraoral radiographs, which precludes its routine use in determining the WL.[11] Therefore, choosing a safer method could be controversial.

A few studies have been performed on the impact of ERR on the accuracy of WL determination of EALs and CBCT.[12,13] With the increase in the use of CBCT in endodontic treatments, we decided to compare the accuracy of the three different modalities (CBCT, digital radiograph, and EAL) in root canal WL determination in teeth with ERR method in an *in vitro* study.

MATERIALS AND METHODS

This *in vitro* study was conducted on 54 permanent mature, signal canal in single-rooted anterior human teeth (extracted for periodontal or orthodontic reasons with no caries). The teeth were free of any root resorption, significant curve, and fracture.

All the sample teeth were cleaned and disinfected with 5.25% sodium hypochlorite (Hypo-Endox, Morvabon, Iran). Then, the samples were soaked in 0.9% saline solution. and stored in the refrigerator that maintained a temperature between 36°F (2°C) and 46°F (8°C) for 24 h.

The teeth were numbered consecutively, and then the crown of each anterior tooth was flattened using a flat diamond bur (D and Z, Switzerland) with a high-speed handpiece to produce a flat stable reference point for measuring the WL. A standard access cavity was prepared with a high-speed fissure bur (Tizkavan, Tehran, Iran) on each tooth.

For simulation of ERR, 3 mm of the apical end of each tooth was placed in 65% nitric acid for 24 h. Then, the teeth were rinsed with distilled water for 2 min. The actual WL of each root was measured by placing a K-File #10 (Mani, Utsunomiya, Japan) until the tip was observed at the apical foramen (resorption level), and then the file was removed from the root canal. The distance from the file tip to the base of the rubber stop (on the flatted crown) was measured using a caliper with an accuracy of 0.1 mm (Mitutoyo, Tokyo, Japan) for the actual WL as the gold standard.

Teeth were then embedded up to the cement–enamel junction in an alginate mold prepared according to the manufacturer's instructions. The WL was measured by Root ZX EAL (J. Morita Co., Kyoto, Japan). The WL was measured with K-file #15 (Mani, Utsunomiya, Japan) inserted into the canal and the rubber stop set to the flattened reference point. On the screen, the K-file was moved apically until the "APEX" signal was observed on the screen, and then the instrument was withdrawn until the display showed the 0.5 mm mark. Both gold standard and EAL WL were recorded by the first observer, and then the procedure was repeated by a second observer to eliminate observer bias. Both observers were two board-certified endodontics with at least 12 years of experience.

Teeth were then mounted in a dry human mandible using pink wax (Polidental, Cotia, São Paulo, Brazil) and 27 digital intraoral images were taken using a VistaScan phosphor plate system (Dürr Dental, Bietigheim-Bissingen, Germany) with 66 kVp, 8 mA, and 0.16 s.

For having a parallel technique, a 30 cm long cylindrical collimator with a film holder, Rinn-Endo-Ray film holder (Dentsply/Rinn XCP Corporation, Elgin, IL, USA), was used for digital periapical radiographs. The tube was set at a distance 2 cm from the dry mandible, as well as vertical angulation of 0° and horizontal of 90°, and the object-detector distance of 1 cm with a fixed wax locator.

Using Scanora 5.0 software (Soredex, Helsinki, Finland), the WL of each tooth was measured on a 22″ medical monitor (LG, Seoul, Korea) (6900 × 1440 pixels, 32 bits). The length was measured from the flattened edge of the tooth to the coronal border of the ERR [Figure 1].

The teeth mounted in the dry mandible were then scanned by the Galileo comfort 3D imaging unit (Sirona Dental System Inc., Bensheim, Germany) with 15 cm × 15 cm field of view (85kvp, 28 mAs) and 0.3 voxel size, VO1 resolution with GALAXIS viewer version 1.944 (ID2) software (SICAT GmbH and Co.KG) 6 mandible CBCT image was taken. The WL was measured from the flattened edge of the tooth to the coronal border of the ERR [Figure 2].

Two oral maxillofacial radiologists with a minimum of 10 years of experience were told to concentrate on all saved images.

During the image evaluation, the oral maxillofacial radiologists viewed the images separately in randomized order one image at a time in a quiet semidark room. The use of image manipulation tools (i.e., contrast and brightness adjustments) was not allowed, except for zooming.

The analysis of data was performed using SPSS software (version 23.0, Chicago, IL, USA). Intraclass correlation coefficient (ICC) was used to assess interobserver agreement. One-way ANOVA was used to investigate the significant differences between groups. The accuracy of measurements was compared at a significant level of $P < 0.001$.

RESULTS

To compare the measuring accuracy, the mean WLs of all methods (Gold standard, EAL, digital radiography, and CBCT) were compared. Although the mean ± standard deviation (SD) of actual WL was 16.00 ± 2.24, the mean ± SD of WLs determined by CBCT, EAL, and digital radiography were 15.38 ± 2.19, 15.52 ± 2.32, and 16.83 ± 2.20, respectively. Table 1 shows the mean, SD, and confidence interval for all methods.

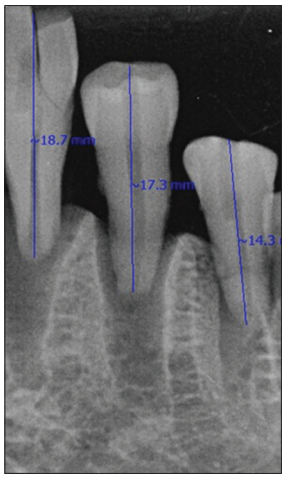

Figure 1: Periapical view of mounted teeth with working length measurement.

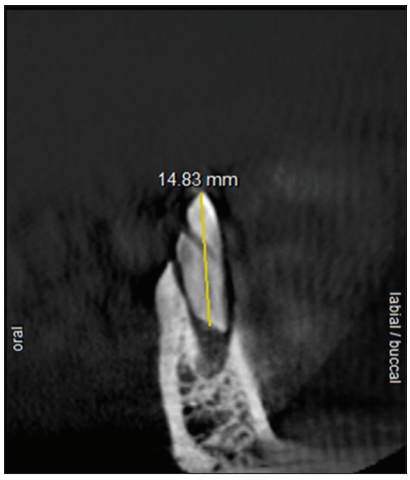

Figure 2: Cross-sectional view in cone-beam computed tomography of mounted teeth with working length measurement.

A significant difference was observed between the mean WL of all methods and the gold standard WL ($P < 0.001$). Using ICC, there was a significant agreement between the observers. There was no significant difference in the way the two examiners (endodontics/oral maxillofacial radiologists) determined the WLs [ICC was >92%, $P < 0.001$, Table 2].

DISCUSSION

Successful endodontic treatment depends on multiple factors including determining the exact WL. There are several methods to determine the WL for root canal therapy. EALs and intraoral periapical radiography

Table 1: Summary of the mean working length (mm) obtained from each method

Method	Mean±SD	CI	
		Lower band	Upper band
Actual length (gold)*	16.00±2.24	15.39	16.62
CBCT	15.48±2.19	14.78	15.98
Digital radiography	16.83±2.20	16.03	17.23
Apex locator	15.52±2.32	14.89	16.16

*Gold standard. SD: Standard deviation; CI: Confidence interval; CBCT: Cone-beam computed tomography

Table 2: Pairwise comparison and *P* value for actual length, cone-beam computed tomography, digital radiography, and apex locator length

Pairwise comparison	*P* (*t*-test)	ICC value	*P***
Actual length - CBCT	<0.001	0.968	<0.001
Actual length - digital radiography	<0.001	0.928	<0.001
Actual length - apex locator	<0.001	0.982	<0.001
CBCT - digital radiography	<0.001	0.938	<0.001
CBCT - apex locator	0.019	0.982	<0.001
Digital radiography - apex locator	<0.001	0.951	<0.001

***P*<0.001 statistical significance. ICC: Intraclass correlation coefficient; CBCT: Cone-beam computed tomography

are the most common methods to determine the WL in routine clinical practice.[4,7] However, many studies have shown that CBCT and EALs can detect root perforation like ERR.[14,15] According to the literature, EAL is able to locate the apical constriction even when it is destroyed.[16] In this study, three different methods including EAL, CBCT images, and periapical digital radiographs have been compared *in vitro* with the actual WL in teeth with ERR.

This study showed that there was a significant difference between the actual mean WL and the EAL, digital periapical radiography, and CBCT mean WL. Among the three methods, EAL was the closest to the actual root canal WL, followed by CBCT. The digital periapical radiography measured the WL much more than the actual WL.

The results of the present study showed that EAL and CBCT were the most accurate methods used to determine the WL in teeth with ERR. This was in line with the findings of previous studies.[17-19] Üstün *et al*.[20] reported that in teeth with large periapical lesions (which can cause root resorption) the measurement of the root canal WL by CBCT was as reliable as EAL, and no significant differences were observed. This study showed that EAL was more reliable than other methods to determine the WL in teeth with ERR. It has been showed that the existence of root resorption did not affect the accuracy of WL determination in the Root ZX apex locator.[21] In a study done by Özata *et al*.,[22] they indicated that EAL was more reliable in WL determination than CBCT and digital periapical radiography.

Our study also showed that the digital periapical radiography was less accurate method for evaluating the exact WL of teeth with ERR. Digital periapical radiography showed the WL much more than the actual WL as over obturation has less success in endodontic treatment.[23]

Kumar *et al*. reported that the Root ZX apex locator was more accurate than intraoral periapical radiographs in determining the WL of the teeth.[21]

Periapical radiography with parallel technique reduces the dimensional distortion in the final radiographic image, but due to its two-dimensional nature, it has limitations in determining the actual WL. Alterations in the buccal and lingual aspects of the root for instance in root perforation and ERR can affect the exact position of the apex which may lead to errors in determining the accurate WL.[24]

CBCT is an expensive diagnostic method with higher radiation exposure but can overcome the limitation of periapical radiographs, particularly on the buccal and lingual aspects of the root, especially where there are no root-filling materials and one can avoid the beam-hardening artifacts of solid materials. Sousa Melo *et al*.[25] suggested that there was a significant difference between different CBCT voxel sizes in detecting early-stage ERR. CBCTs with smaller voxel size were more dedicated when investigating the early stage of ERR during orthodontic treatment.

In a study by de Morais *et al*. on single-rooted teeth diagnosed with apical periodontitis, the accuracy of WL determination using CBCT, conventional periapical radiographies, and EAL, WL using CBCT images was precise when compared to the periapical radiographic method and EAL.[18] The apical limits such as ERR for WL accurate determination had influenced the outcome of root canal treatment, and it has been the subject of discussions in various studies.[26]

Different imaging systems, apex locators, sample size, observer's performance, and the amount of ERR that are not completely predictable due to the use of acid to stimulate root resorption can influence the detection of ERR and might explain the discrepancy between

reports. In addition, future studies should examine different apex locator systems, CBCT machines, software to study other sizes, and types of ERR.

CONCLUSION

This *in vitro* study showed that there was a significant difference between the actual mean WL and the EAL determined by digital periapical radiography and CBCT mean WL. The results suggest that the accuracy of the Root ZX apex locator and CBCT for determining the WL in the presence of ERR was higher than the intraoral periapical radiographs. Thus, EAL is the closest to the actual WL in teeth with ERR, further research and advances may make this technique a suitable choice for WL determination, or a combination of the CBCT and EALs may be the future choice for WL measurement in teeth with ERR.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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