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ORIGINAL ARTICLE

Accuracy of Working Length Measurement Using Cone Beam Computed Tomography at Three Field of View Settings, Conventional Radiography, and Electronic Apex Locator: An *Ex-vivo* Study

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ABSTRACT

Objective: Determining the working length (WL) in root canal treatment facilitates the treatment prognosis. The introduction of apex locators and new devices in dentistry influenced this consideration. This comparative study evaluated the accuracy of working length measurement by cone beam computed tomography (CBCT) in three fields of view (FOVs), conventional radiography, and the apex locator Raypex 5.

Methods: The descriptive-analytical study was performed on 40 mandibular premolar teeth that met the inclusion criteria. Direct observation under the microscope was considered the gold standard and compared with measurements by the electronic apex locator, CBCT at three field of view settings and periapical images. The results were analyzed by paired t-tests and Wilcoxon tests. The level of significance was set at 0.05 ($p=0.05$).

Results: Results showed that the CBCT at 5×5 FOV ($p=0.733$) and Conventional radiography($p=0.001$) achieved the working lengths with the highest and lowest accuracy, respectively. In addition, the difference between actual and measured working length using conventional radiography was significant ($p<0.05$).

Conclusion: According to the results of this study, CBCT images at different FOVs and those taken by the apex locator Raypex 5 can be used as a reliable method for estimating the working length.

Keywords: Apex locator, cone-beam computed tomography, conventional radiography, field of view, working length

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HIGHLIGHTS

- Available CBCT images with smaller voxel sizes would be beneficial in determining endodontic working length.
- CBCT images at smaller FOVs can be reliable for estimating the working length.
- The radiation dose for endodontic CBCT scans is lower due to the smaller FOV

INTRODUCTION

The efficacy of root canal treatment is contingent upon many factors, with none more pivotal than the precise determination of the working length (1, 2). An inaccurate assessment of this crucial parameter can yield suboptimal clinical outcomes characterized by excessive or inadequate root canal instrumentation and subsequent insufficient filling (3, 4). This inherent challenge is exacerbated by the intrinsic variability in the position and topographical features of the apical constriction and apical foramen, rendering the precise localization of the apical constriction an elusive clinical objective (5).

To enhance accuracy, dental practitioners routinely employ conventional radiography and apex locators as primary tools for working length measurement. However, it is imperative to acknowledge the intrinsic limitations of conventionla oral radiography, chief among them being the generation of two-dimensional representations of three-dimensional anatomical structures. This feature introduces potential distortions in the image's shape and dimensions (6, 7).

The precision of conventional radiography in determining working length has been documented at a modest 50.6% (1, 8). In response to the inherent limitations of conventional radiography, the electronic apex locator has emerged as a valuable adjunctive tool for refining working length determination (9). Notably, apex locators have garnered acclaim for their capacity to furnish high levels of accuracy in this context (10, 11). Furthermore, the adoption of electronic apex locators offers the distinct advantage of repeatability without imposing any harm to the patient.

Increased attention towards apex locators within the dental community indicates their evolving utility. Newer generations of apex locators have surmounted previous limitations, particularly their sensitivity to moisture within the root canal (7, 9).

In recent decades, the advent of cone beam computed tomography (CBCT) in endodontics represents a significant advancement. CBCT surpasses conventional radiography in its capacity to produce three-dimensional (3D) images instead of two-dimensional (2D) representations. Also, because heightened precision arises from eliminating superimposed anatomical structures, this technological shift enables a more enhanced evaluation of the morphological structure of the root canal system (12, 13).

In CBCT, similar to all other computed tomography (CT) techniques, the fundamental components of the resulting grayscale images are the pictures' element values (pixel values). A computer algorithm reconstructs the CBCT image to create a 3D dataset of volumetric elements and isotropic voxel resolutions. The main determinants of the nominal voxel size in a CBCT image are the matrix and pixel size of the detector. Detectors with smaller pixels capture fewer X-ray photons per voxel, producing more image noise. Consequently, higher resolution CBCT imaging can be designed to use higher dosages to achieve adequate signal-to-noise ratio and improved diagnostic image quality (14). A high correlation was found between the actual length, the smallest voxel size, and the highest CBCT measurements. (15).

Field of view (FOV) refers to the scan volume of a particular CBCT unit. In most cases, the larger the FOV, the larger the voxels with a fixed pixel count, resulting in a loss of resolution. Previous studies have reported discrepancies in CBCT measurements depending on the position of objects within the FOV. The linear measurement accuracy is lower in the periphery than in the central CBCT field of view (16). In endodontics, using a smaller FOV and smaller voxels to produce a higher resolution is recommended to increase the image quality while reducing the noise, technical artifacts, and the relatively low dose (17).

Conversely, the literature provides evidence suggesting that electronic measurement techniques surpass CBCT in terms of precision when determining the working length (18). Also, a field of view (FOV) and voxel size assume critical significance in the context of CBCT image quality, ultimately leading to the potential for achieving a notably enhanced level of diagnostic accuracy (4, 15, 16). Due to the availability of different FOVs, it is essential to select optimal imaging protocols and the most appropriate FOV to determine the working length. So, this study aimed to compare the accuracy of CBCT in three fields of view, conventional radiography, and electronic apex locator in determining the working length.

The null hypothesis tested was that there is no difference between the accuracy of CBCT in three field of view settings, conventional radiography and electronic apex locator, in determining the location of the apical constriction under *in vitro* conditions.

MATERIALS AND METHODS

This research was approved on Golestan University of Medical Sciences 2018-12-23 under ethics number IR.GOUMS.REC.1397.185. This study was conducted according to the Declaration of Helsinki.

Sample Selection

Forty single-canal mandibular premolar teeth, extracted for orthodontic purposes, were selected according to the following inclusion and exclusion criteria.

Inclusion Criteria

1. Teeth display a mature apex.
2. Single-canal mandibular premolar teeth.
3. Teeth are characterized by an intact and unaltered root structure.
4. Teeth meet the specific orthodontic extraction requirements.

Exclusion Criteria

1. Teeth lacking a mature apex or presence of obvious root resorption
2. Teeth displaying the presence of metallic restorations.
3. Mandibular premolar teeth with more than one canal.
4. Teeth exhibiting dental caries, canal calcification, and dental anomalies.
5. Teeth demonstrating significant occlusal attrition, rendering them unsuitable for inclusion in the study.

The samples were then placed for 15 min in 5.25% hypochlorite solution to disinfect and remove the remaining tissues and then stored in Normal saline solution. The access cavity was prepared with the help of high-speed Fissure bur (Komet Dental, Lemgo, Germany) with cooling. The top of the cusp was ground down to create a uniform reference surface. The canal orifices were located with an endodontic probe. A #15 K-file was passed through the end of the root canal to ensure the canal was not blocked. Taking into account the empirical evidence that employing the perflaring technique enhances the precision of working length measurements (19, 20), the canal preflaring procedure was conducted by an endodontist. This procedure involved using a rotary device (X-Smart; Dentsply Maillefer) with SX and S1 ProTaper files (Dentsply Maillifer, Ballaigues, Switzerland). The preflaring process extended these files to approximately two-thirds of the working length, utilizing brushing movements to achieve the desired effect. The canals were washed with 3 mL 6% sodium hypochlorite and 3 mL saline 0.9% to remove pulp and dentine residues. All of the specimens underwent assessment for working length determination and were organized into four distinct groups as follows:

Actual Working Length Determination

The stainless-steel K-file #15 (MANI.Inc, Japan) with a silicone stop was placed in the canal to determine the actual working length. Viewing the file tip passing through the apical foramen was confirmed under the stereomicroscope (Leica Microsystems, Wetzlar, Germany) with a magnification of 4X. Then, the file was partially retracted until the tip was located at the apical foramen edge, so the silicon rubber stop was fixed precisely at the buccal cusp tip. The distance between the rubber stop and the file tip was measured. Considering the location of apical constriction at a distance of 0.5 mm from the major apical foramen (21), the measured distance was subtracted by 0.5 mm to obtain the canal's working length.

Electronic Working Length Measurement

For electronic determination of the working length by Raypex 5 (VDW GmbH, Munich, Germany), a polymethylmethacrylate (PMMA) cylindrical with two holes for tooth and lip attachment was used. Normal saline was used to establish the electrical circuit and to simulate the oral environment inside the cylinder. A manual stainless-steel K-file #15 (MANI. Inc., Japan) with a silicon rubber was attached to the file holder and slowly passed through the apex area. The file was adjusted to the narrowest point of the canal specified by the apex locator according to the manufacturer's instructions (utilize the apex mark). Then, the silicon rubber was fixed at the incisal edge, and finally, the length of the removed file was measured by a ruler with an accuracy of 0.5 mm. This length was recorded as the electronic working length (Fig. 1).

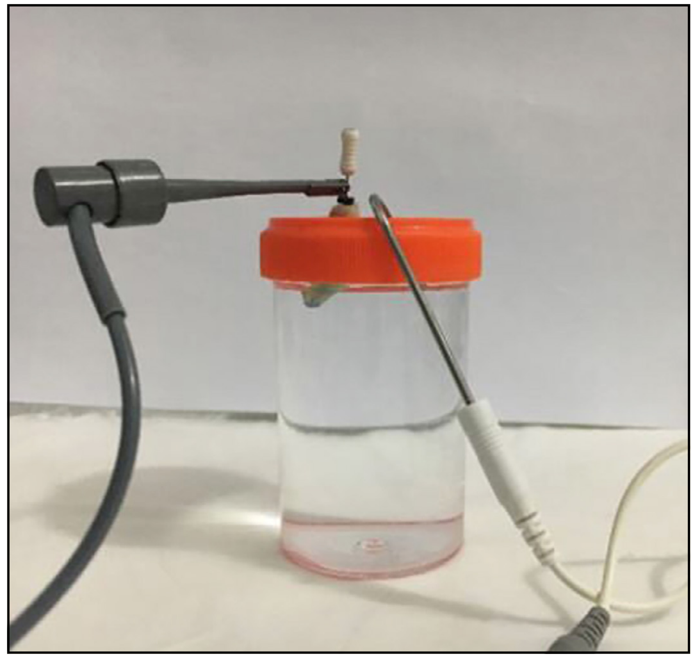

Figure 1. A Normal saline cylinder to simulate the oral environment and the electrical circuit. The rubber stop was secured on the cusp tip

CBCT Working Length Measurement

The teeth were first mounted in self-curing rectangular cubic blocks of polymethylmethacrylate (PMMA) with a length of 30 × 30 mm and a height of 40 mm. For the simulation technique designed to replicate the periodontal ligament (PDL) environment, wax served as the isolation medium to establish a gap for the PDL surrounding the tooth root. The root was briefly immersed for two seconds in liquefied base-plate wax (Kerr Dental, Orange, CA, USA) heated to 65°C, ensuring complete coverage of the root up to the demarcation on the root at the CEJ level. This process created a wax layer approximately 0.2 to 0.3 mm in thickness around the root, as described by Marchionatti et al. (22). A cubical brass mold was filled with autopolymerizing acrylic resin (Acropars 200; Marlic Dental, Tehran, Iran) to mimic the alveolar bone surrounding the tooth. The tooth was affixed to the vertical rod of a dental surveyor (Cucciolo; Mariotti, Forli, Italy) using sticky wax to maintain its vertical orientation within the acrylic resin mold. Subsequently, the filled mold was positioned on the surveyor base directly beneath the tooth-vertical rod assembly. The tooth-rod assembly was gradually lowered into the acrylic resin-filled mold until it reached the demarcating point. The tooth was securely held in this position until the acrylic resin fully polymerized.

During the preparation of CBCT exposure, the tooth-mounted acrylic blocks are placed on the same point using the unit holding plates used in scanning laboratory tests. Thus, they are fixed in the horizontal and vertical planes.

The images of each tooth were prepared using a Carestream dental (CS 8100 3D, Family Carestream) with an exposure time of 15 s, a voltage of 90 kV, and a current intensity of 3.20 mA at a fixed voxel size of 150 μm at three field of view settings: (1) 5×5 cm^2, (2) 8×5 cm^2 and 9×8 cm^2. With the exception that in the smaller field of view (5×5 cm^2), an electric current of 5 milliamps was used. In this way, the amount of radiation dose in each of the three fields of view is 665 mGy/cm^2, 685 mGy/cm^2, and 1098 mGy/ cm^2, respectively.

The prepared images were analyzed by Carestream imaging software. The panoramic image was first reconstructed from a CBCT image 1.1 mm thick. Then, the cross-sectional images were cut with a thickness of 150 μm across the tooth. This range produces approximately 55 cuts. According to the examination of the obtained sectional cuts, images in each central cut with the best representation of canal morphology were selected and measured by two experienced endodontists.

Measurements were obtained for all sections by tracing the canal from the coronal reference point to its terminus. A calibrated ruler of CS software (Carestream imaging software) was used to measure the length from the incisal reference point to 0.5 mm from the apical foramen.

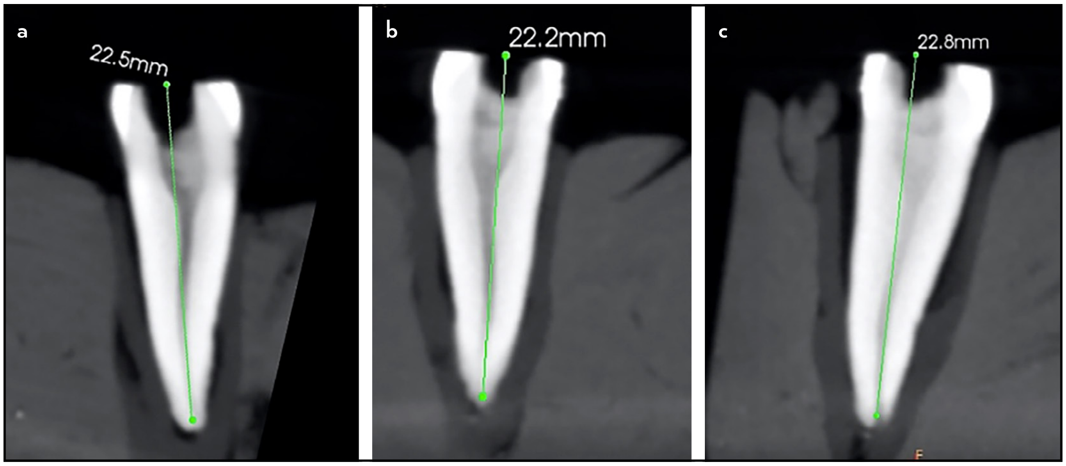

Figure 2. Determination of the working length of a tooth by (a) CBCT at FOV of 5×5 cm, (b) CBCT at FOV of 5×8 cm and (c) CBCT at FOV of 8×9 cm

CBCT: Cone beam computed tomography, FOV: Fields of view

Working Length Measurement Using Conventional Radiography

Conventional radiographic images were acquired by Planmecaprox (PlanmecaOy, 00880 Helsinki, Finland) with an exposure time of 0.02 sec, a voltage of 70 kV, and a current intensity of 8 mA and an analog image receiver (SkydentE, Czech Republic) of size 2. The object's distance to the radiation source and the analog image receiver was 20 cm and 20 mm, respectively. The images were first prepared using a parallel technique, and then the approximate length was determined by matching a k-file #15 on the radiograph. By inserting the desired file with the estimated length inside the canal and fixing it, another paralleling image was obtained, and the correct working length was recorded by placing the file at a distance of 0.5 mm from the radiographic apex. The results were then recorded as the measured canal length. Figure 2 shows the radiographic working length of a mounted tooth by CBCT at three different FOVs.

Statistical Analysis

The studied variables were analyzed with descriptive statistics such as mean and standard deviation with the help of SPSS 19 (IBM SPSS Statistics 19, SPSS Inc., Somers, NY, USA). Interclass Correlation Coefficient (ICC) was used to evaluate the measurement correlation between two examiners. Shapiro Wilk test was used to assess the normality of data. Moreover, the paired t-test and Wilcoxon test were used for normal and abnormal distributed data to compare the accuracy of the methods with the actual working length with an alpha error of 0.05 and a power of 0.95. Therefore, a significance level of 0.05 was considered in this study.

RESULTS

To assess the validity of CBCT across the three FOV settings, conventional radiography, apex locator, and actual working length, an Interclass Correlation Coefficient (ICC) of 0.948 was computed. The findings revealed that CBCT with an 8×9 FOV, CBCT with an 8×5 FOV, CBCT with a 5×5 FOV, conventional radiography, and the apex locator accurately determined the root canal length corresponding to the actual length in 31.6%, 36.8%, 55.3%, 47.4%, and 84.2% of cases, respectively (Table 1). The Shapiro-Wilk test for normal distribution was applied to compare the actual working length with the measured length. It was established that data obtained from CBCT at an 8×9 FOV, conventional radiographs, and the apex locator adhered to a normal distribution (p-value>0.05). Conversely, data acquired through CBCT with 5×5 and 5×8 FOVs differed from normality. Subsequently, the paired t-test and Wilcoxon test were employed to compare the data exhibiting normal and non-normal distribution patterns. The outcomes of these statistical tests are presented in Table 2.

The results indicated that CBCT with a 5×5 FOV (p-value of 0.733) and conventional radiography (p-value of 0.001) exhibited the highest and lowest levels of accuracy, respectively, in determining working lengths. Furthermore, it was observed that there was a statistically significant difference between the actual and measured working length when employing conventional radiography (p-value<0.05).

DISCUSSION

Determining the exact working length and maintenance during treatment is crucial in successful endodontic therapy. This determination will prevent damage to the periapical tissues during canal preparation and canal filling (23). Endodontic problem-solving depends on the images' radiographic quality to evaluate the anatomy of the tooth and surrounding tissues. Conventional radiography, despite limitations such as the overlap of anatomical structures and 2D images, is still commonly used by clinicians to determine the working length (24). Different generations of apex locators are used in root canal treatment to reduce the need for multiple radiographs during treatment (25). However, the ultimate working length is usually determined by considering both methods: observing the anatomy of the tooth by radiography and electronic measurement (26). With the introduction of CBCT in endodontics, its accuracy and high image quality have received attention from researchers (4, 15, 27). CBCT devices can reconstruct the dental canal image in all three coronal, sagittal, and axial planes (28) and display a 3D image of the desired area in computer software (18). Understanding the 3D morphology of

TABLE 1. The number and percentage of samples in the range of ±0.5% and ±1% of the actual length

Variation from the actual length	CBCT (FOV 8×9)	CBCT (FOV 5×8)	CBCT FOV (5×5)	Conventional radiography	Electronic apex locator
Matched on the apical constriction	12 (31.6)	14 (36.8)	21 (55.3)	18 (47.4)	32 (84.2)
At a distance of ±0.5 from the apical constriction	29 (76.3)	33 (86.8)	36 (94.7)	36 (94.7)	38 (100)
At a distance of ±1 from the apical constriction	32 (84.2)	36 (94.7)	38 (100)	37 (97.4)	38 (100)

CBCT: Cone beam computed tomography, FOV: Fields of view

TABLE 2. Descriptive statistics, the mean difference between actual length and that measured by CBCT, conventional radiography, and apex locator

Method	The length measured by different methods		Difference with the actual length		Test	
	Mean	Standard deviation	Mean	Standard deviation	Statistics	p
Actual working length	18.92	2.1764	–	–	–	–
CBCT (FOV 5×5)	18.97	2.1590	0.0522	0.9137	0.342[a]	0.733
CBCT (FOV 5×8)	18.75	2.1268	-0.1710	0.8160	-0.882[a]	0.378
CBCT (FOV 8×9)	19.17	2.1666	0.1184	0.3755	1.944[b]	0.06
Conventional radiography	19.03	2.0649	0.2763	0.3620	4.705[b]	0.001
Electronic apex locator	18.94	2.1002	0.026	0.1995	0.803[b]	0.422

[a]: Wilcoxon test statistics, [b]: Paired t-test statistics. CBCT: Cone beam computed tomography, FOV: Fields of view

the dental canal increases the accuracy of working length determination (13). In CBCT images, the voxels are isotropic and vary from 0.075 µm to 0.4 mm, which allows for cropping and examination of all three planes (24, 29). However, due to the high dose of the ionizing beam, the CBCT image is not used to determine the working length. It is only indicated if the clinical examination with conventional radiography are insufficient for diagnosis. So, reducing the irradiated area is essential to reduce the dose imposed on the patient while providing images of higher resolution (13). Due to the variability of FOV size in different devices, three different FOVs were investigated to introduce the smallest FOV suitable for determining the working length (27). The accuracy of CBCT in different FOVs with different voxel sizes has been investigated (4, 15). So, images with different voxel sizes were prepared in this study to compare the effect of different FOVs.

The apical constriction has been reported in the literature as the ending point of canal termination, which was a distance of 0.5 mm to 2 mm from the apical foramen (1, 3). Because of the anatomical variability, using the file's position at 0.5 mm from the radiographic apex may be expected to result in erroneous measurements.

This study was conducted *in vitro* for convenience, better control of variables, and direct observation of the apical constriction. Other studies have shown the lower accuracy of conventional radiography in determining the length of curved canals (30). Hence, teeth without root curvature were used in this study. According to the literature, the presence of in-canal disinfectants can affect the accuracy of apex locators (18). Therefore, all measurements in this study were performed after drying the canal to remove any moisture.

According to Vieyra et al. (31), the accuracy of apex locator Raypex 5 and conventional radiography in determining the working length corresponding to the apical constriction was 61.6% and 32.14%, respectively. Sadeghi et al. (32) reported 70% and 50% accuracy for the apex locator Raypex 5 and conventional radiography at a distance of ±0.5 from the apical constriction, respectively. In our study, the length measured by the apex locator and conventional radiography matched the apical constriction, respectively, in 84.2% and 47.4% of cases. Unlike conventional radiography, the apex locator is reliable for determining the working length (p-value<0.05).

Aktan et al. (15) and Jeger et al. (13) examined the accuracy of CBCT images and found that CBCT is a reliable method for determining the working length. Janner et al. (27) compared the accuracy of CBCT with standard methods in determining the working length. They found that CBCT and the apex locator can successfully evaluate root canal working length. Iandolo et al. (33) evaluated the anatomy of sections of the apices of maxillary premolars 1 mm from the radiographic apex utilizing high-resolution cone beam computed tomography. In the case of endodontic treatments of maxillary premolars, a pre-operative high-resolution 3D CBCT is performed to know the measurements of the last apical millimeter of the roots. These studies comply with the results of the present study. According to the statistical results of our study, there is no significant difference between the measured working length using the Raypex-5 apex locator and CBCT in all three fields of view (p-value>0.05). Yilmaz et al. (4) evaluated the accuracy of determining working length using an electronic apex locator, periapical radiography, and CBCT recorded at different voxel sizes and FOV settings in extracted human teeth. They found that accuracy increased with smaller voxel sizes without statistically significant differences (p>0.05). Cheng et al. (28) and Vieyra et al. (31) examined the accuracy of CBCT in measuring the working length. According to their results, the accuracy of CBCT in determining the length corresponding to the apical constriction was 69.7%. An accuracy of 64.6% and 95.5% were obtained at a distance of ±0.5 and ±1 from the apical constriction. With a reduction in field size, there is a decrease in noise and scattered radiation, resulting in improved spatial resolution of the root canal anatomy and more accuracy and repeatability in working length determination. In this study, the voxel size and kilovoltage (KVp) were consistent across all three fields, but the milliampere (mA) in two larger FOVs (8×5 cm^2 and 9×8 cm^2) was lower than the field of view (5×5 cm^2). The dose levels in the two larger fields of view were 1098 mGy/cm^2 and 685 mGy/cm^2, respectively. In comparison, the dose amount for the field of view (5×5 cm^2) was equal to 665 mGy/cm^2 (4, 18).

Apex locator, CBCT 5×5 FOV with a p-value more than 0.05, and conventional radiography with a p-value of 0.001 achieved the working lengths with the highest and lowest accuracy, respectively. So, the null hypothesis was rejected. Our results showed that CBCT could be used to determine the working length with an accuracy of 31.6% to 100% in different FOVs. We also confirmed that the accuracy of CBCT images increases by decreasing the FOV area. CBCT at 5×5 FOV showed the best accuracy in working length measurement. Limiting the investigation area, reducing radiation dose, and scattering radiation improve the safety and quality of images (32, 34).

Although CBCT offers several advantages over conventional radiography by addressing various limitations, the higher radiation dose associated with CBCT than conventional radiography restricts its routine usage (35). Specifically, the "as low as reasonably practicable" (ALARP) principle often discourages using CBCT except in cases where it provides exceptional diagnostic value. In endodontology, CBCT imaging is more of an exceptional practice than a standard procedure. However, patients frequently present with pre-existing CBCT scans, which can be advantageous for acquiring additional three-dimensional radiographic information. For example, it enables the visualization of the precise location and dimensions of the pulp chamber in three dimensions, facilitating minimal-invasive access-cavity preparation. Additionally, CBCT images can aid in determining the endodontic working length (WL) (36, 37).

It is important to note that this research was conducted *in vitro*, which may not encompass the potential errors that could arise in clinical settings when calculating the root canal length.

It is important to note that this study results are specific to the particular CBCT system evaluated, assuming an absence of streak and beam hardening artifacts, motion artifacts, and anatomic noise originating from the jaw structures. Further investigations with high evidence are warranted to validate the outcomes.

CONCLUSION

Considering the limitations inherent in this study, it can be concluded that CBCT images obtained using the voxel size of 0.15mm^3 and FOV of a 5×5 cm out performed those acquired with larger FOV settings and intraoral conventional radiography in determining the endodontic working length. The measurements obtained using an apex locator demonstrated superior accuracy compared to CBCT and periapical images.

Disclosures

Ethics Committee Approval: The study was approved by the Golestan University of Medical Sciences Ethics Committee (no: IR.GOUMS.REC.1397.185, date: 23/12/2018).

Authorship Contributions: Concept – A.I.; Design – A.I., E.K.; Supervision – A.I.; Funding – F.G.; Materials – F.G.; Data collection and/or processing – F.G., A.M.A.; Data analysis and/or interpretation – F.G., A.M.A.; Literature search – A.I., E.K.; Writing – A.I., E.K.; Critical review – E.K.

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