Endodontic Working Length Measurement Using Cone-beam Computed Tomographic Images Obtained at Different Voxel Sizes and Field of Views, Periapical Radiography, and Apex Locator: A Comparative *Ex Vivo* Study

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Abstract

Introduction: The aim of this study was to evaluate the accuracy of working length determination by using an electronic apex locator, periapical radiography, and cone-beam computed tomographic (CBCT) imaging obtained at different voxel sizes and field of views (FOVs) in extracted human teeth. **Methods:** Thirty extracted human mandibular premolar teeth were used. The electronic working length measurements were performed by using an electronic apex locator (Root ZX; J Morita Corp, Kyoto, Japan). Five different image sets were obtained as follows: (1) CBCT imaging: 40 × 40 mm FOV, 0.080 mm^3 (FOV_{40}); (2) CBCT imaging: 60 × 60 mm FOV, 0.125 mm^3 (FOV_{60}); (3) CBCT imaging: 80 × 80 mm FOV, 0.160 mm^3 (FOV_{80}); (4) CBCT imaging: 100 × 100 mm FOV, 0.250 mm^3 (FOV_{100}); and (5) periapical digital radiography. Direct measurements performed with an electronic digital caliper were considered as the gold standard and compared with the electronic apex locator, CBCT, and periapical image measurements. Data were analyzed using a 2-way analysis of variance test. Significance level was set at $P < .05$. **Results:** There was no significant difference between or within operators in intraoral radiographs ($P > .05$ and the Gage R&R value was <30%). There were significant differences between and within operators for CBCT images ($P < .05$ and Gage R&R value was >30%). There were significant differences in the methods in terms of mean differences from the gold standard ($P < .05$). **Conclusions:** This study showed that available CBCT scans with different FOVs can be used for working length measurement. *(J Endod 2017;43:152–156)*

Key Words

Apex locator, cone-beam computed tomography, endodontics, measurement, radiography, working length

Significance

Determination of the correct working length is clinically very important in terms of endodontic treatment success. The present study assessed the effect of different CBCT FOVs and voxel sizes on the determination of the working length in comparison with common clinical and radiologic techniques. Available CBCT scans at all voxel sizes smaller than 0.3 mm^3 can be helpful in the determination of the endodontic working length.

Determination of the correct working length is clinically very important to perform accurate root canal treatment. Overestimation of the endodontic working length may cause overinstrumentation of the root canals, whereas underestimation of the working length may result in insufficient root canal preparation (1–3). Apical constriction is considered the ideal end point of the root canal system. This is also known as the narrowest point in the canal and contains the smallest diameter of blood supply that creates the smallest wound site, enabling the best healing condition. The apical constriction is located 0.5–1 mm superior to the major foramen on the root surface (1–3). The apical foramen may be located laterally and at a distance of up to 3 mm from the anatomic apex (1–3). An electronic apex locator and periapical radiography are the most frequently preferred tools for root canal working length determination in routine clinical practice. Apex locators are useful adjuncts in locating the working length during endodontic therapy with an ability of reported accuracy ranging between 55% and 93% (4–6). Intraoral radiography has some limitations because of its 2-dimensional nature in determining the endodontic working length. Some drawbacks including distortion, magnification, and superimposition may negatively affect determination of the accurate working length (5). In addition, periapical radiography fails to provide the accurate location of the apex in cases in which an eccentric foramen is present (6). Cone-beam computed tomographic (CBCT) images are able to show root canal angles and define the location of the major foramen, which is not identifiable with sufficient precision in periapical radiography (7). CBCT devices are able to acquire

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multiplanar reformatted reconstructions of the root canal morphology, which can be viewed by the clinician on a computer display simultaneously. CBCT systems operate by focusing a cone-shaped beam on a 2-dimensional detector that performs 1 pass or less around the patient's head to produce a series of images (8–10). The main advantages of CBCT imaging when compared with medical computed tomographic imaging are the size of the scanner, the cost, and its ease of use for dental applications along with lower effective radiation doses (8–10). However, generally, CBCT imaging delivers far greater effective doses than intraoral imaging. Most CBCT units include multiple field of views (FOVs) and voxels that can better address a variety of specific tasks. A "voxel" describes the smallest distinguishable box-shaped part of a 3-dimensional image. FOV is used to refer to the scan volume of a particular CBCT unit (8–10). Voxel size and FOV are detrimental in terms of image quality and scanning and reconstruction times of CBCT images. In CBCT imaging, voxels are isotropic, and images can be constructed in any plane with high fidelity. The availability of different FOVs makes it possible to select the most appropriate FOV for a specific application. Because larger FOVs result in higher effective radiation doses, as a rule, smaller FOVs are recommended for imaging a quadrant or single tooth, whereas larger FOVs are preferred for large surgical operations (8–10).

Generally, in routine clinical practice, apex locators are considered the most reliable and precise tools in order to determine the working length (11). However, apical anatomic complexities may affect the performance of electronic apex locators, resulting in unstable readings and inappropriate measurements. It was also reported that the lateral positioning of the apical foramen or the presence of multiple apical foramen may negatively affect the measurement accuracy of electronic apex locators (6, 12, 13).

Considering radiation concerns, authors suggested the use of available CBCT images taken for other purposes as an adjunct to common clinical techniques for working length determination. Limited FOV CBCT imaging with small voxel sizes had the potential to improve the spatial resolution of root canal anatomy in any chosen viewing plane, enabling accurate and repeatable working length determination (14). Another study, using an *in vitro* setup, found that the apex locator was more accurate than CBCT imaging in the determination of working length measurement (15).

To our knowledge, no previous study assessed the effect of different FOVs and voxel sizes on determining the working length in comparison with common clinical and radiologic techniques. Therefore, the aim of the present study was to evaluate the accuracy of working length determination by using an electronic apex locator, digital periapical radiography, and CBCT imaging with different voxels and FOVs.

Materials and Methods

Sample Selection

Approval of the use of extracted teeth along with a dry mandible was obtained through the Gülhane Military Medical Academy Dental Science Center, Ankara, Turkey (local ethical committee review number 50687469-1491-415).

Thirty freshly extracted human mandibular premolar teeth without calcified canals and dental anomalies were selected. The teeth were immersed in 10% formalin and then cleaned with scalers to remove organic debris and deposits. All teeth were kept in 5.25% sodium hypochlorite for 2 hours and then stored in sterile 0.9% saline solution until they were used. Thereafter, all the teeth were numbered, and the root canal access cavities were prepared. The pulp tissue of the canals was removed using barbed broaches.

Working Length Determination

The actual length of the root canal was measured by inserting a size 15 K-file in the canal until the file tip became visible at the apical foramen under 5× magnification using an operating microscope (Leica Microsystems, Wetzlar, Germany). When the file tip was just visible at the apical foramen, the silicone stop was placed at the reference point, and then the file was removed from the canal. The distance from the base of the silicone stop to the file tip was measured with an electronic digital caliper (Allendale Electronics Ltd, Hertfordshire, UK) with fine pointed jaws and a measuring range of 0–200 mm (0–8.0 inch) and a resolution of 0.01 mm (0.0005 inch). The average of 2 measurements was considered as the reference standard. The real working length was established by subtracting 0.5 mm from the actual length. The working length was obtained by using an electronic apex locator (Root ZX; J Morita Corp, Kyoto, Japan). The corresponding teeth were embedded into alginate to the level of the cementoenamel junction. The root was kept in that position until the alginate had completely set. All measurements were made at intervals of 2 hours, with the alginate maintained in sufficiently humid conditions. During electronic measurement, the labial clip of the corresponding locator was inserted into the alginate. The file that was attached to the file holder was gently inserted until the display read "00" (13). Then, the rubber stop was placed at the coronal reference, and the working length was measured with an electronic digital caliper (Allendale Electronics Ltd). The average of 2 measurements was considered as the reference standard. The actual working length and electronic working length measurements were conducted by an experienced endodontist (10 years).

Imaging

For imaging procedures, each tooth was placed in the appropriately prepared empty mandibular right and left first premolar socket of a dry mandible. The dry mandible was covered with 1.5 cm red wax as a soft tissue equivalent material (16). Images of each tooth were taken with an X-ray generator (Evolution X3000 2 C/1 New Life; New Life Radiology, Grugliasco, TO, Italy) operated at 70 kVp and 8 mA and an image exposure time of 0.20 seconds. Digital periapical images were recorded using a photostimulable phosphor plate (PSP) digital intraoral system (Digora Optime; Soredex, Tuusula, Finland), which includes a feature that automatically erases residual image signals. Image recording was set at a 40-μm pixel size, 14-bit grayscale, and 12.5 lp/mm spatial resolution. A "size 2" imaging plate was used, and the exposed phosphor plates were scanned immediately after exposure. *Ex vivo* periapical imaging was performed using standardized paralleling technique equipment with rectangular collimation (Rinn Manufacturing Company, Elgin, IL) with a focus receptor distance of 40 cm. Pulpal root canal, dentin, and enamel visibility were used as indicators of optimal image quality.

CBCT images of the teeth inserted in the mandibles were obtained using a CMOS flat panel detector, variable FOV CBCT unit (3D Accuitomo 170, J Morita Mfg Corp) operating at 80 kVp, 2.0 mA, and an exposure time of 17.5 seconds at 4 different FOVs and voxel sizes (nominal cubic mm resolution [mm^3]):

1. 40 × 40 mm FOV, 0.080 mm^3 (FOV_{40});
2. 60 × 60 mm FOV, 0.125 mm^3 (FOV_{60});
3. 80 × 80 mm FOV, 0.160 mm^3 (FOV_{80}); and
4. 100 × 100 mm FOV, 0.250 mm^3 (FOV_{100}).

Data Collection

All images (periapical and CBCT) were evaluated separately by 2 calibrated observers in a dimly lit room on a 15.6-in laptop monitor