The Validity of Cone-beam Computed Tomography in Measuring Root Canal Length Using a Gold Standard

Yu-Hong Liang, DDS, Lan Jiang, DDS,* Chen Chen,* Xue-Jun Gao, DDS, PhD,* Paul R. Wesselink, DDS, PhD,† Min-Kai Wu, MSD, PhD,† and Hagay Shemesh, DDS, PhD†*

Abstract

Introduction: The distance between a coronal reference point and the major apical foramen is important for working length determination. The aim of this *in vitro* study was to determine the accuracy of root canal length measurements performed with cone-beam computed tomographic (CBCT) scans using a gold standard. **Methods:** A total of 162 teeth (198 root canals) in 16 dry human dentulous mandibles were scanned using a 3DX-Accuitomo CBCT scanner (Morita 3DX; J Morita Mfg Corp, Kyoto, Japan). The root canal length was measured with CBCT data. All teeth were extracted atraumatically and endodontically accessed; the root canal length was measured blindly using a #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) and served as the gold standard. **Results:** The mean absolute difference of the CBCT-based root canal length from the gold standard was 0.46 mm (95% confidence interval, 0.41–0.50 mm). Only in 9 of 198 (4.5%) roots did the difference between the CBCT-based root canal length and the gold standard exceed 1 mm. **Conclusions:** CBCT-based root canal length measurements are accurate and reliable when compared with a gold standard. *(J Endod 2013;39:1607–1610)*

Key Words

Apical foramen, cone-beam computed tomography, coronal reference point, root canal length

From the *Department of Cariology and Endodontology, Peking University School and Hospital of Stomatology, Beijing, China; and †Department of Endodontology, Academic Center of Dentistry Amsterdam, University of Amsterdam and VU University, Amsterdam, The Netherlands.

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Address requests for reprints to Dr Yu-Hong Liang, Department of Cariology and Endodontology, Peking University School and Hospital of Stomatology, Beijing 100081, China. E-mail address: leungyuhong@sina.com

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Instrumentation and root filling procedures should not be performed beyond the apical foramen (AF) (1) and should be limited to 0–2 mm shorter of the AF (2, 3). In clinical studies, the apical extension of root filling has been found to significantly influence periapical healing (4–6), and the AF was used to distinguish flush, long, and short fillings (6).

However, the AF could not be detected on 2-dimensional radiographs, and, therefore, the radiographic apex had to be used as an apical reference point in most cases (2). The AF deviates from the root apex in up to 92% of teeth (7) and has been reported to be up to 3.8 mm short of the radiographic apex in all aspects of the root (8, 9).

In cases in which the AF is short of the apex and the radiographic apex is used as the apical reference point during root canal treatment, the assumed working length might be too long, which could negatively influence the treatment outcome. It has been reported that when instrumentation was limited to 0–2 mm from the radiographic apex, overinstrumentation occurred in 22% of molars and 51% of premolars (2). Therefore, using the radiographic apex as an apical reference point often results in overinstrumentation. When the radiographic apex was used to determine the apical extent of root fillings, it appeared that these estimations were often incorrect (5).

Although the accuracy of modern apex locators is higher when compared with periapical radiographs (PAs) in determining the root canal length (10–12), usually both methods are used. In some cases, 2-dimensional PAs overestimated the root canal length (12, 13), and apex locators may have given an incorrect reading (12). In contrast, cone-beam computed tomographic (CBCT) imaging has the potential to locate the AF and show root canal anatomy in 3 dimensions. When CBCT scans are available for diagnosis and treatment planning, clinicians should take advantage of all the information available (14, 15). Although root canal length values measured with preexisting CBCT scans have been compared with those measured by an electronic apex locator (14, 15), the precision and reliability of the CBCT-based root canal length measurements have not been compared with a gold standard. The purpose of this study was to assess the precision of root canal length measurements on CBCT images using a gold standard.

Materials and Methods

Sample Selection

Sixteen human dentate mandibles were provided by the Department of Anatomy, Peking University, Beijing, China. The exact age, sex, and storing time in formalin was unknown. The skin and soft tissues were carefully removed. Each mandible was soaked for 90 minutes in warm soapy water (Blue Moon; Blue Moon Corp, Guangzhou, China) to increase the moisture content and the resilience of the mandible for the subsequent extraction of teeth (16).

Radiographic Technique

Baseline straight projection PAs were obtained using the following standardized conditions: a dental x-ray machine (Planmeca Intra, Helsinki, Finland) was operated at 70 kV, 10 mA, and a 20-cm distance from the digital imaging plate (Cranex Optime Intraoral Unit; Soredex, Tuusula, Finland). Teeth with root canal fillings, periapical lesions, root resorptions, or fractures were discarded.

CBCT scans were acquired with a 3DX-Accuitomo CBCT scanner (J Morita Mfg Corp, Kyoto, Japan), with a 4 × 4-cm field of view selection and operating conditions of 70 kVp, 3–5 mA, and an exposure time of 17.5 seconds. Prosthetic dental wax in a thickness of 12 mm was used as a soft-tissue substitute (17). CBCT scanning was performed with the 3D Accuitomo XYZ Slice View Tomograph (J Morita Mfg Corp) with a basic voxel size of 0.125 mm. CBCT data were reconstructed with 0.25-mm-thick slices at an interval of 0.125 mm using the system's proprietary software.

Measurements on CBCT Scans

CBCT slices were first reformatted to vertically position the root canal of each analyzed tooth to visualize the tooth cusp or incisal edge, pulp chamber, AF, and, when possible, the whole length of the canal in 1 single slice. The cursor of the z-plane was moved to have an overview of the number and the direction of curvatures of the roots. Then, the image was sliced again with the y-axis in the curvature direction, making the angle of the root curvature larger in the y-plane and smaller in the x-plane. These alignments optimized the visualization of complete root canal anatomy (15).

Alignment and measurements of CBCT images were performed by a radiologist experienced in reading CBCT scans using specialized software (i-Dixel, J Morita Mfg Corp). The selected image of the y-plane was enlarged 4 times. In anterior teeth, the root canal length was defined as the distance between the most incisal edge in the projected midline of the pulp cavity and the AF (14, 15). In posterior teeth, the distance between the closest cuspidal edge in the projected extension line of the cervical one-third canal and the AF was defined as the length (Fig. 1). The measurements followed the visible canal deviation in the y-plane, allowing measurements of nonlinearly shaped canals.

AF Location and Gold Standard

All roots were atraumatically extracted and immediately inspected. Roots showing apical resorptions and/or root fractures were discarded. Baseline PAs were provided to an endodontic resident to evaluate the tooth anatomy before preparing the access cavity. The pulp cavity was accessed, and a smooth, unimpeded path to the coronal one-third canals was created. After having reached patency with a #08 K-file, a #10 file (Dentsply Maillefer, Ballaigues, Switzerland) was passively advanced toward the apex until the tip of the instrument was visible at the AF with a magnifying glass (CT-200F; Mydream Electronic, Shanghai, China) by 5× magnification (18). A rubber stop was then carefully adjusted to the same cuspal edge coronal reference as determined in the CBCT measurement to enable comparison. The distance between the rubber stop and the instrument tip was measured by a caliper to the nearest 0.01 mm and served as the gold standard (Fig. 1).

Root apices were examined under a stereomicroscope (ZOOM-630E; Chang-Fang Optical Instrument Co, Shanghai, China) at 40× magnification to determine the location of the AF and the deviation from the apex. The AF was defined as the opening with the largest diameter on the apex confirmed by the visualization of an endodontic file tip penetrating through the canal (19). The distance from the apex to the most occlusal point of the AF was measured with a micrometric scale of 0.01-mm accuracy with a stereomicroscope (20, 21). Deviation of the AF from the apex was further classified as central or lateral.

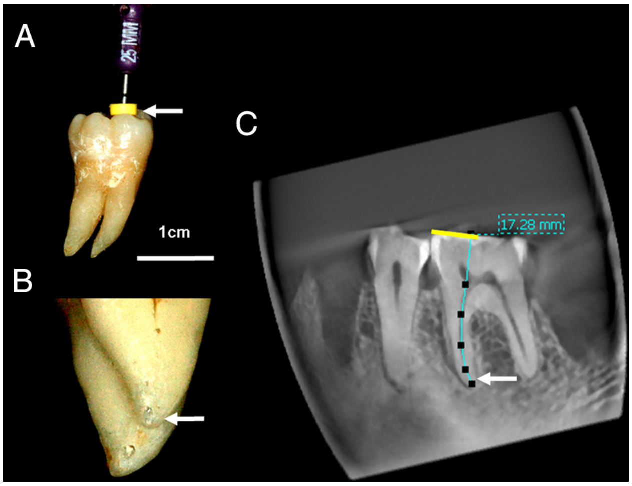

Figure 1. (*A* and *B*) Gold standard measurements of a mandibular molar between (*A*) the coronal reference point (*arrow*) and (*B*) the AF (*arrow*). (*C*) The CBCT length was defined as the distance between the cuspal edge (*yellow line*) in the projected extension line of the cervical one-third canal (*blue line*) and the major foramen (*arrow*).

Calibration

Two observers, an experienced radiologist and an endodontic resident, were calibrated with CBCT scans of 10 anterior and 10 posterior teeth before this investigation. They were informed of the selection of reference points. The root canal length was measured by a radiologist using the CBCT data. An endodontic resident was blinded to the CBCT scans and evaluated the gold standard length measurements and deviation of the AF from the apex. Each measurement was performed independently and blindly by the examiners twice with a 1-week interval between measurements.

Statistics

The intraclass correlation coefficient was used to test the intraexaminer reliability of the measurement values. The Pearson correlation coefficient (γ) was calculated based on the data from the CBCT scans and file measurements to evaluate the accuracy of CBCT measurements. The level of significance was set at alpha = .05.

Results

Forty-six teeth were excluded from this study because of root fractures, canal obliterations, root resorptions, or impactions. A total of 162 teeth (198 root canals), 74 anteriors, 46 premolars, and 42 molars, from 16 dentulous mandibles in human cadavers were finally analyzed.

The intraclass correlation coefficient was 0.982 for the CBCT length measurements and 0.960 for the gold standard, respectively ($P < .001$). In 44% of the specimens, the AF deviated from the root apex (≤1.9 mm). The data analysis for the differences between CBCT measurements and the gold standard is summarized in Table 1. The Pearson correlation coefficient (γ) comparing the values was 0.977 ($P < .01$) (Table 1). The mean absolute difference and mean percentage difference were 0.46 mm (95% confidence interval [CI], 0.41–0.50 mm) and 2.4% (95% CI, 2.1%–2.6%), respectively. The proportion of CBCT measurements within a ±0.5-mm difference from the gold standard was 64.6%. Overall, only in 4.5% (9/198) did the difference between CBCT measurements and the gold standard exceed 1 mm. The largest mean absolute difference of 0.51 mm was in molars (95% CI, 0.44–0.59 mm). In teeth with a central opening AF, the mean difference was 0.47 mm (95% CI, 0.41–0.54 mm), and in teeth with a lateral opening AF, the mean difference was 0.44 mm (95% CI, 0.37–0.50 mm). When using a range of −1 mm to +0.5 mm as deviation tolerance, the accuracy was 85.4%. CBCT imaging overestimated

TABLE 1. The Absolute Differences between CBCT-based Root Canal Length and Gold Standard Measurements

Tooth type (canals)	Mean differences: Mean absolute differences (range) (mm)	Mean differences: Mean absolute percentage differences (range) (%)	95% confidence interval: Absolute differences (mm)	95% confidence interval: Percentage differences (%)	Pearson correlation coefficient (α = 0.01)
Anteriors (*n* = 74)	0.42 (0.01–1.23)	2.1 (0–6.3)	0.35–0.49	1.7–2.4	0.987
Premolars (*n* = 46)	0.42 (0.03–1.12)	2.1 (0–5.5)	0.32–0.51	1.6–2.5	0.958
Molars (*n* = 78)	0.51 (0–1.33)	2.8 (0–6.3)	0.44–0.59	2.4–3.2	0.936
Total (*N* = 198)	0.46 (0–1.33)	2.4 (0–6.3)	0.41–0.50	2.1–2.6	0.977

Mean absolute differences = | (CBCT-based root canal length) − (gold standard) |. Mean percentage differences = | (CBCT-based root canal length) − (gold standard)/(gold standard)|.

the length in 10% of the canals (20/198) with a range of 0.5–1 mm beyond the AF.

Distributions of the differences of the values are presented in Figure 2. CBCT imaging underestimated the length in 129 canals (65%) and overestimated it in 58 canals (30%). The maximum difference between CBCT measurements and the gold standard was 1 mm in overestimations and −1.3 mm in underestimations.

Discussion

In the present *in vitro* study, a strong correlation between CBCT length measurement and the gold standard was found (Table 1), which indicates the high reliability of CBCT measurements. Forty-four percent of the roots had an AF that deviated from the apex, but the difference between CBCT measurements and the gold standard was comparable for roots with a central opening and a lateral opening AF. This indicated that the location of the AF did not influence the accuracy of CBCT measurements.

The high intraclass correlation coefficient comparing the 2 CBCT measurements repeated with a 1-week interval showed the high reproducibility of the present method. The coronal reference point may not be identical on CBCT slices and the actual cuspidal edge. This inconsistency could explain the difference between CBCT measurements and the gold standard. The largest mean absolute difference of 0.51 mm was observed in molars (95% CI, 0.44–0.59 mm). The difficulty to map and visualize the complete canal in 1 single slice on CBCT scans when multiple curvatures exist explains why molars showed the largest difference between CBCT and gold standard measurements.

Concerning the clinical relevance of CBCT length measurements, a previous report (12) shows that in 15% of the cases, an electronic apex locator cannot reliably measure the root canal length. Such is the case with open apices, crown metallic restorations, obliteration/inaccessibility of canals (22), and root fracture and perforation (23). In some patients with a cardiac pacemaker, the use of an apex locator could be contraindicated. In these situations, the radiographic working length is relied on. However, PAs could not always detect the AF, and, thus, length measurements could be unreliable because of superimpositions (2, 18, 24). In contrast to PAs, CBCT imaging can display both the mesiodistal and buccolingual shape of root canals and is able to show the AF (14, 15).

Adhering to the ALARA (As Low As Reasonably Achievable) principle (25), it should be emphasized that findings from the present study cannot be used as an indication for CBCT usage. Only in those cases in which CBCT data are already available for diagnosis and the treatment plan is using these data for length determination recommended; this can even prevent additional radiographs during treatment. Under the limitations of this study, CBCT-based root canal length measurements were accurate and reliable.

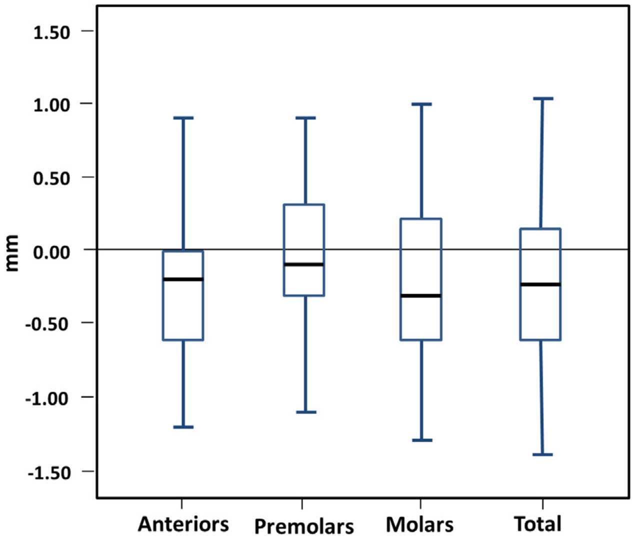

Figure 2. Box plots showing the median (*black bold line*) and the 10th, 25th, 75th, and 90th percentiles of the difference of CBCT length determination from the AF. (A positive value means that the CBCT scan overestimated the length, namely, that a file would penetrate through the apical foramen if inserted to that length.)

Acknowledgments

The authors deny any conflicts of interest related to this study.

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