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


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.

Keywords

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

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.

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.

Intraoral Unit; Cranex, Optime

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.

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.

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.

Supported by Specific Research Project of Health Pro Bono Sectors, Ministry of Health, China (201002017).

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: leungyuahong@ sina.com

Copyright © 2013 American Association of Endodontists.

http://dx.doi.org/10.1016/j.joen.2013.08.001
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 a 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, where possible, the whole length of the canal in a 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 extension line of the cervical one-third canal and the AF was defined as the length between the closest cuspidal edge in the projected extension line of the distance between the most incisal edge in the projected midline of enlarged 4 times. In anterior teeth, the root canal length was defined as a soft-tissue substitute (17). CBCT scanning was performed with the 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 micrometer 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.

**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 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 micrometer 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.

**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...
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 –1.5 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.

**Acknowledgments**

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

**References**


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

<table>
<thead>
<tr>
<th>Tooth type (canals)</th>
<th>Mean absolute differences (range) (mm)</th>
<th>Mean absolute percentage differences (range) (%)</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anteriors (n = 74)</td>
<td>0.42 (0.01–1.23)</td>
<td>2.1 (0–6.3)</td>
<td>Absolute differences (mm) 0.35–0.49</td>
</tr>
<tr>
<td>Premolars (n = 46)</td>
<td>0.42 (0.03–1.12)</td>
<td>2.1 (0–5.5)</td>
<td>Absolute differences (mm) 0.32–0.51</td>
</tr>
<tr>
<td>Molars (n = 78)</td>
<td>0.51 (0–1.33)</td>
<td>2.8 (0–6.3)</td>
<td>Absolute differences (mm) 0.44–0.59</td>
</tr>
<tr>
<td>Total (N = 198)</td>
<td>0.46 (0–1.33)</td>
<td>2.4 (0–6.3)</td>
<td>Absolute differences (mm) 0.41–0.50</td>
</tr>
</tbody>
</table>

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