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Chapter 4
The Validity of Cone-beam Computed Tomography in Measuring Root Canal Length using a Gold Standard

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Abstract

Introduction: The distance between a coronal reference point and 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 tomography (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). 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 and served as a gold standard. Results: The mean absolute difference of CBCT-based root canal length from the gold standard was 0.46 mm (95% confidence interval: 0.41-0.50 mm). Only in 9/198 (4.5%) roots the difference between CBCT-based root canal length and the gold standard exceeded 1 mm. Conclusions: CBCT-based root canal length measurements are accurate and reliable when compared to a gold standard.
Introduction

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

However, AF could not be detected on 2-dimensional radiographs and therefore, the radiographic apex has 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 where 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, over-instrumentation occurred in 22% of molars and 51% of premolars (2). Therefore, using the radiographic apex as an apical reference point often results in over-instrumentation. When the radiographic apex was used to determine the apical extent of root fillings, it appeared that these estimations were often wrong (5).

Although the accuracy of modern apex locators is higher when compared to periapical radiographs (PA) in determining the root canal length (10-12), usually both methods are used. In some cases, 2-dimensional PA’s could overestimate the root canal length (12, 13) and apex locators may give an incorrect reading (12). In contrast, CBCT has the potential to locate 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 electronic apex locator (14, 15), the precision and reliability of the CBCT-based root canal length measurements have not been compared to a gold standard. The purpose of this study was to assess the precision of the root canal length measured on CBCT images using a gold standard.
Materials and Methods

Sample selection
16 human dentate mandibles were provided by the Department of Anatomy of Peking University, Beijing, China. The exact age, gender and storing time in formalin was unknown. The skin and soft tissues were carefully removed. Each mandible was soaked for 90 min in warm soap water (Blue Moon, Blue Moon corp, Guang-zhou, China) to increase the moisture content and the resilience of the mandible for the subsequent extraction of teeth (16).

Radiographic technique
Baseline straight projection PA were obtained using standardized conditions: a dental X-ray machine (Planmeca Intra, Helsinki, Finland) was operated at 70 KV, 10 mA, and 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 4x4-cm field of view (FoV) selection and operating conditions of 70 kVp, 3 to 5 mA and an exposure time of 17.5 s. Prosthetic dental wax in thickness of 12 mm was used as a soft tissue substitute (17). CBCT scan was performed with 3D Accuitomo XYZ Slice View Tomograph (Morita, Kyoto, Japan) 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 in order to visualize the tooth cusp or incisal edge, pulp chamber, AF, and when possible, the whole length of the canal in one single slice. The cursor of the Z plane was moved to have an overview of the number and the direction of the 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 the 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; Morita, Kyoto, Japan). The selected image of Y plane was enlarged 4 times. In anterior teeth, 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 cuspal edge in the projected extension line of the cervical 1/3 canal and the AF was defined as the length. Measurements followed the visible canal deviation in the Y plane, allowing measurements of non-linearly shaped canals.

**AF location and gold standard**

All roots were atraumatically extracted and immediately inspected. Roots demonstrating apical resorptions and/or root fractures were discarded.

Baseline PA’s 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 1/3 canals was created. After having reached patency with a 08 K-file, a # 10 file, 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 x5 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.

Root apices were examined under a stereomicroscope (ZOOM-630E; Chang-Fang Optical Instrument Co., Shanghai, China) at 40x magnification to determine the location of AF and the deviation from apex. AF was defined as the opening with the largest diameter found in the root apex confirmed by the visualization of an endodontic file tip penetrating through the canal (19). The distance from the anatomical apex to the most occlusal point of the major foramen was measured using a micrometric scale with an accuracy 0.01mm of the stereomicroscope (20, 21). Deviation of the major foramen from the anatomical apex was 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 reference points.
selection. Root canal length was measured by a radiologist from CBCT data. An endodontic resident was blinded to the CBCT scans and evaluated the gold standard length measurements and deviation of AF from the apex. Each measurement was performed independently and blindly by the examiners twice with a 1 week interval.

Statistics
Intraclass correlation coefficient was used to test the intra-examiner reliability of the measurement values. The Pearson correlation coefficient (\( \gamma \)) was calculated on the data from the CBCT and file measurements to evaluate the accuracy of CBCT measurements. The level of significance was set at \( \alpha = .05 \).

Results
46 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<0.001). In 44% of the specimens, the AF deviated from the root apex (\( \leq 1.9 \) mm). The data analysis for the differences between CBCT measurements and gold standard is summarized in Table 1. The Pearson correlation coefficient (\( \gamma \)) comparing the values was 0.977 (p<0.01) (Table 1.). The mean absolute difference and mean percentage difference was 0.46mm (confidence interval, 95%, 0.41-0.50mm) and 2.4% (confidence interval, 95%, 2.1%-2.6%), respectively. The proportion of CBCT measurements within ±0.5mm difference from the gold standard was 64.6%. Overall, only in 4.5% (9/198) the difference between CBCT and gold standard exceeded 1 mm. The largest mean absolute differences 0.51mm was in molars (confidence interval, 95%, 0.44-0.59 mm). In teeth with a central opening AF, the mean difference was 0.47mm (confidence interval, 95%, 0.41-0.54mm), and in teeth with a lateral opening AF, 0.44mm (confidence interval, 95%, 0.37-0.50mm). When using a range of -1 mm - +0.5mm as deviation tolerance, the accuracy was 85.4%. CBCT overestimated the length in 10% of the canals (20/198) with a range 0.5 -1
mm beyond the AF.

Distributions of the differences of the values are presented in Fig.1. CBCT underestimated the length in 129 canals (65%) and overestimated in 58 canals (30%). The maximum difference between CBCT measurements and gold standard was 1mm in overestimations and -1.3mm 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. 44% of the roots had AF that deviated from the apex, but the difference between CBCT-measurements and gold standard was comparable for roots with a central opening and a lateral opening AF. This indicated that the location of AF did not influence the accuracy of CBCT measurements.

The high intraclass correlation coefficient comparing the 2 CBCT measurements repeated with 1 week interval showed the high reproducibility of the present method.

The coronal reference point may not be identical on CBCT slices and on the actual cuspidal edge. This inconsistency could explain the difference between CBCT and gold standard. The largest mean absolute difference 0.51mm was observed in molars (confidence interval, 95%, 0.44-0.59 mm). The difficulty to map and visualize the complete canal in one single slice on CBCT scans when multiple curvatures exist explain why molar showed the largest difference between CBCT and gold standard measurements.

Concerning the clinical relevance of CBCT length measurements, a previous report (12) shows that 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 (23), or root fracture and perforation (24). In some patients with a cardiac pacemakers, the use of apex locator could be contraindicated. In these situations, radiographic working length is relied upon. However, PA could not always detect AF and thus length measurements could be unreliable due to superimpositions (2, 18, 22). In contrast to PA, CBCT can display both the mesiodistal and buccolingual shape of root canals.
and is able to demonstrate AF (14, 15).

Adhering to the ALARA principle (25), it should be emphasized that findings from the present study could not be used as an indication for CBCT usage. Only in those cases where CBCT data are already available for diagnosis and treatment plan, utilizing this data for length determination is recommended and will even prevent additional radiographs during the treatment.

Under the limitations of this study, CBCT-based root canal length measurements were accurate and reliable.
Table 1 The Absolute Differences Between CBCT-Based Root Canal Length and Gold Standard

<table>
<thead>
<tr>
<th>Tooth type (canals)</th>
<th>Mean Absolute Differences (range) (mm)</th>
<th>Mean Absolute Percentage Differences (%)</th>
<th>95% Confidence Interval</th>
<th>Pearson Correlation Coefficient (α=0.01)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anteriors (n=74)</td>
<td>0.42 (0.01-1.23)</td>
<td>2.1%</td>
<td>0.35-0.49</td>
<td>1.7%-2.4%</td>
</tr>
<tr>
<td>Premolars (n=46)</td>
<td>0.42 (0.03-1.12)</td>
<td>2.1%</td>
<td>0.32-0.51</td>
<td>1.6-2.5%</td>
</tr>
<tr>
<td>Molars (n=78)</td>
<td>0.51 (0-1.33)</td>
<td>2.8%</td>
<td>0.44-0.59</td>
<td>2.4-3.2%</td>
</tr>
<tr>
<td>Total (n=198)</td>
<td>0.46 (0-1.33)</td>
<td>2.4%</td>
<td>0.41-0.50</td>
<td>2.1-2.6%</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) |
Figure 1
Box plots illustrate the median (black bold line), 10th, 25th, 75th, 90th percentiles of the difference of CBCT length determination from AF (positive value means that the CBCT overestimated the length, namely that a file would penetrate through the apical foramen if inserted to that length).
Figure 2

(a-c): (a-b) Gold standard measurements of a mandibular molar between the coronal reference point (a) (arrow) and apical foramen (b) (arrow). (c): CBCT length was defined as the distance between the cuspal edge (yellow line) in the projected extension line of the cervical 1/3 canal (blue line) and the major foramen (arrow).
References


