A comparative analysis of periapical radiography and cone-beam computerized tomography for the evaluation of endodontic obturation length

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Objective. The aim of this study was to determine the consistency and inconsistency between the periapical radiography (PR) and cone-beam computerized tomography (CBCT) in evaluating the length of root canal obturations (RCOs) in vivo.

Study design. Thirty-six maxillary and mandibular first and second molars yielding 109 obturated root canals with available PR and CBCT images were analyzed. The inclusion criterion was that the RCO extended 0-2 mm short of the radiographic apex on PR images. Teeth having root canal calcification, apical resorption, or poor quality PR/CBCT images were excluded. Agreement and disagreement between the 2 imaging modalities for obturation length were analyzed using the χ² test.

Results. A total of 30.3% of the RCOs evaluated by PR as having adequate length were diagnosed by CBCT to have inadequate length. Among these, 13.8% were overextended and 16.5% underextended as diagnosed by CBCT. When the distance from the filling tip to the radiographic apex was 0.5 to 1 mm on the PR image, the discordance rate was the lowest (11.1%) in all evaluated distance groups, significantly lower than with distances of 0-0.5 mm and 1.5-2 mm (P < .01). When RCOs were diagnosed as terminating at the facial/lingual side, overextension was the main evaluation result by CBCT in the disagreement evaluation with PR and significantly more frequent than those at the mesial/distal/central side (P < .01).

Conclusions. CBCT evaluated 30.3% of the RCOs with radiographically adequate length as inadequate. When the RCOs radiographically terminated 0.5-1 mm short of the apex, the evaluation rated adequate for obturation length was comparatively reliable. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;112:383-389)

One of the keys to successful root canal therapy is to adequately obturate the prepared root canal space.1,2 It has been suggested that the apical extension of the root filling is significant in determining the success of endodontic therapy.3,6 Underextension may leave space for colonization and proliferation of bacteria, whereas overextension may become a constant source of irritation, causing an inflammatory response in the periapical tissue.3,4,7-9 Either could lead to failure of the endodontic treatment.7,10 The level of termination of root canal instrumentation and obturation is one of the controversies of endodontic therapy. Many researchers hold that root canal treatment should terminate at the cementodontinal junction (CDJ),11,12 which often coincides with the pulp and periodontal tissue junction and accordingly has minimal contact with periapical tissue.13,14 However, the CDJ is merely a histologic location and cannot be identified under current clinical circumstances.15-17 The apical constriction (minor foramen), the apical portion of the root canal having the narrowest diameter,18 has been advocated by most researchers as the end point of treatment.19,22 However, some studies show that the apical constriction has several morphologic variations,23 and it is often absent,24,25 especially after instrumentation. It is generally agreed that instrumentation and obturation should be limited to within the root canal system.3,16 Thus, the apical (major) foramen, the most apical opening of the canal, is also considered a useful landmark for terminating the root canal obturation (RCO).26 Periapical radiography (PR) is the most commonly used method in clinical practice to evaluate the quality of RCO. However, neither the apical constriction nor the apical foramen is discernible on the PR. The only measuring point that can be viewed on PRs is the anatomic (radiographic) apex.27,28

Generally, RCO is considered to be clinically satisfactory and designated to be adequate if the tip of the filling material is 0-2 mm short of the radiographic apex.
Nevertheless, it is well known that the anatomic location of the apical foramen varies between individuals. A predetermined distance range hardly reflects the true individual anatomy. In reality, an obturation classified as satisfactory by radiographic determination might have filling materials beyond or short of the apical foramen because of individual anatomic variation. On the other hand, because the PR is a 2-dimensional (2D) representation of a 3-dimensional (3D) structure, radiographic estimation of RCO is challenging for the difficulty of distinguishing superimposed features.

Recently, cone-beam computerized tomography (CBCT) was introduced to endodontics as a noninvasive tool for disease diagnosis and morphologic evaluation. It can produce 3D images of dentoalveolar regions at a lower radiation dose and cost and at a higher resolution than conventional computerized tomography. Many studies have demonstrated its accuracy in diagnosing and measuring. Simon et al. indicated that CBCT might provide a more accurate diagnosis than biopsy when evaluating large periapical lesions (e.g., granuloma vs. cyst). Michetti et al. registered a strong to very strong correlation between the data related to areas and Feret diameters acquired by using CBCT and histology. Blattner et al. reported that there was no significant difference in the ability of CBCT scanning to detect the second mesiobuccal canal compared with the criterion standard of clinical sectioning (P > .5). Accordingly, as a 3D imaging technique, CBCT is expected to be valuable in accurately evaluating the length of endodontic obturations.

The purpose of the present study was to determine the consistency and inconsistency between PR and CBCT in the evaluation of endodontic obturation length in vivo.

MATERIALS AND METHODS

Patients
Thirty-six consecutive patients who had recently undergone root canal therapy for their maxillary or mandibular first or second molars in the Department of Operative Dentistry and Endodontics at the West China College of Stomatology, Sichuan University, Chengdu, China, between October 2009 and April 2010 were enrolled in this investigation. The Root ZX (J. Morita, Tokyo, Japan), an electronic apex locator, was used according to the manufacturer’s instructions in conjunction with PRs to determine the working length. The root canals were then filled to the adjusted working length with gutta-percha cones and AH Plus (Dentsply DeTrey, Konstanz, Germany) using a lateral condensation technique. Inclusion criteria were that: 1) the teeth involved had been examined with both PR and CBCT after completing endodontic therapy; and 2) the tip of the filling material was 0-2 mm short of the radiographic apex on the PR image. Exclusion criteria were: 1) evidence of root canal calcification, apical resorption, immature root apices, root perforation or fracture; and 2) poor-quality PR or CBCT images. Approval by the Ethics Committee of the West China College of Stomatology and an informed consent from each patient were obtained before the investigation.

There were 14 women and 22 men, with a mean age of 35 years (range 17-60 years) in this study. We analyzed 36 teeth representing 109 root canals. The distribution of teeth types is presented in Table I.

Radiographic techniques
PR images were taken by an experienced operator using a paralleling technique with a film holder (XCP; Rinn, Elgin, IL). Silicone rubber impression material (Exafine putty type; GC, Tokyo, Japan) was used to ensure that a reproducible radiograph could be taken. All radiographs were taken with a dental x-ray machine (Gendex Expert; DC, Des Plaines, IL) operating at 65 kV and 7 mA and an exposure time of 0.25 seconds for maxillary and 0.20 seconds for mandibular teeth. Dental intraoral E-Speed films (Kodak; Carestream Health, Rochester, NY) were used. All films were uniformly processed in an automatic processor (Periomat Plus; Dürr Dental, Bietigheim-Bissingen, Germany) with fresh Kodak processing solutions for 5 minutes at 24°C according to the manufacturer’s instructions.

The CBCT images were taken by an experienced operator using a 3D Accuitomo Tomograph (Morita). Operating parameters were 80 kV and 5.0 mA and exposure time 17.5 seconds. The voxel size was 0.125 mm and the slice thickness 1.0 mm. Scans were made according to the manufacturer’s recommended protocol.

Evaluation of images
The PR films were viewed with ×3.6 magnification on a standard viewing box in a dark room. Distances between the tip of the RCOs and the radiographic apex for each root canal were measured with the use of a digital caliper. The E-like markers

<table>
<thead>
<tr>
<th>Jaw</th>
<th>Tooth type</th>
<th>No. of teeth</th>
<th>No. of root canals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxilla</td>
<td>First molar</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Second molar</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Mandible</td>
<td>First molar</td>
<td>20</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Second molar</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>36</td>
<td>109</td>
</tr>
</tbody>
</table>
on the films were used to calibrate the measurement of the PR images to compensate for elongation and foreshortening. When the distances were 0-2 mm, the RCOs were evaluated as adequate and the subjects were enrolled in the study. According to the numeric values of the distances, the RCOs were classified into 4 groups: 1) 0-0.5 mm; 2) 0.5-1 mm; 3) 1-1.5 mm; or 4) 1.5-2 mm.

The CBCT images were analyzed with the built-in software (I-Dixel, one-volume viewer 1.5.0) using a Dell Precision T5400 workstation (Dell, Round Rock, TX) and a 32-inch Dell LCD screen with a resolution of 1,280 × 1,024 pixels in a dark room. Contrast and brightness of images was adjusted with the image-processing tool of the software to ensure optimal visualization. For 3D images, tomographic sections in 3 planes (axial, coronal, and sagittal) were presented, and the observers were able to align the 3 planes at any point by clicking a location of interest on any of the planes. This allowed the location of the root end of the canal space to be determined in the 3 planes. From the CBCT images, we classified each RCO into 1 of 3 categories (Fig. 1): A) overextension, defined as the visible extension of the root end of RCO beyond the root apex surface in >1 of the image planes; B) underextension, defined as the visible presence of canal space between the root end of the RCO and the apex in >1 of the image planes; or C) flush, defined as the root end of RCO terminating at the apex, with neither overextension nor underextension. The flush RCOs were evaluated as adequate and the overextended and underextended RCOs as inadequate. In addition, according to the location of the point where the obturation terminated at the apex, the position of the RCO could be divided into 1 of 3 classes: 1) central; 2) mesial or distal; or 3) buccal or lingual.

Evaluations were carried out by 3 observers (2 endodontists and 1 radiologist) under the same viewing conditions. Before starting, the observers were trained using sample PR and CBCT images of RCOs with various apical extensions. The investigated images were assessed in the following sequence: session 1: all PR images; session 2: all CBCT images (in random order); and session 3: 18 PR (presenting 54 RCOs) and 18 CBCT images (presenting 55 RCOs) randomly picked out and reevaluated to assess intraobserver agreement. There was a 2-week interval between sessions. In each assessment, the observers evaluated the images independently and then discussed their findings to reach consensus. The observation time and number of times for measuring were not restricted.

Fig. 1. A-C, Periapical radiographic images showing root canal obturations (RCOs) as satisfactory (arrows). A1-A3, Cone-beam computerized tomographic (CBCT) images in (1) axial, (2) coronal, (3) sagittal planes. A1-A3, CBCT shows RCO as overextended (arrows). B1-B3, CBCT shows RCO as underextended (arrows). C1-C3, CBCT shows RCO as flush (arrows).
Comparison of the PR and the CBCT techniques for evaluating obturation length in different subgroups was performed using $\chi^2$ test, and the Bonferroni-Holm adjustment was used where applicable. The intraobserver agreement was analyzed with the kappa test. Statistical analysis was performed with SPSS 13.0 (SPSS, Chicago, IL). The significance level was set at .05.

RESULTS

Intraobserver agreement was assessed in 50% (18 of the 36 roots) of the cases for each imaging modality in session 3. The kappa values for intraobserver agreement were 0.852 and 0.804 for PR and CBCT, respectively.

In the present investigation, 69.7% of the root canal obturations (76 of 109 RCOs) were evaluated by both PR and CBCT as adequate, whereas 30.3% (33 of 109 RCOs) were evaluated as adequate by PR but inadequate by CBCT. Among the discordant evaluations, 13.8% were for overextension and 16.5% for underextension, as diagnosed by CBCT. There was no significant difference in concordance or discordance rates between different teeth and root canals (Tables II and III; $P > .05$). However, it was noteworthy that the discordance rate in the mesiobuccal root canals of maxillary molars was as high as 42.9%.

The evaluation disagreement between the 2 imaging modalities was related to the distance between the RCO end point and the radiographic apex measured on PR images. When the distance measured 0.5-1 mm, the discordance rate was the lowest (11.1%) in all evaluated distance groups (Table IV). The results of multiple comparisons showed significant differences for disagreement evaluation when comparing group 2 with group 1 ($P < .01$) or group 4 ($P < .01$). There was no difference between groups 1, 3, and 4. The frequency of overextension evaluation by CBCT was the highest in group 1, showing significant differences compared with groups 2, 3, and 4 ($P < .01$). However, there was an increasing tendency from group 1 to group 4 for underextension evaluation by CBCT, with a significant difference between groups 1 and 4 ($P < .01$). Spearman correlation analysis was performed to determine the correlation between the distance and the disagreement evaluation. The results showed that the disagreement evaluation was significantly correlative with the distance ($r_s = -0.601; P < .01$).

Regarding the location of the root end of the RCO assessed by CBCT, no significant difference between classes 1, 2, and 3 was found for the disagreement between the 2 imaging modalities in evaluating obturation length ($P > .05$; Table V). However, the frequency of overextension evaluation by CBCT in class 3 reached 46.7%, which was obviously higher than in classes 1 or 2. The differences were significant ($P < .01$).

DISCUSSION

Evaluating the length of RCO has been a challenge in clinical endodontics because of the well known shortcomings of PR. CBCT, which can provide 3D information about a given tooth, has proven to be a potential diagnostic tool in modern endodontic practice. The observer can view the different slices of the sagittal, coronal, and axial planes of a tooth without superposition of the anatomic structures. It has been suggested that CBCT is a good method for initial identification of maxillary first molar internal morphology. The apical foramen can be considered to be the region where the canal leaves the root surface next to the periodontal ligament, and CBCT can display the surface of the root and internal root canal space in 3D. In this way, CBCT can roughly locate the apical foramen and accordingly diagnose obturations that extend into periapical tissue or have obvious unfilled canal space. This overcomes the diagnostic limitations of PR for the most part.

There have been few studies on using CBCT to diagnose the apical extension of RCOs, and relevant diagnostic standards have been absent. According to the characteristics of CBCT images and the results of

<table>
<thead>
<tr>
<th>Tooth type</th>
<th>Adequate fill assessed by both PR and CBCT</th>
<th>Adequate fill assessed by PR but inadequate fill assessed by CBCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper first molar</td>
<td>19 (70.4)</td>
<td>4 (14.8)</td>
</tr>
<tr>
<td>Upper second molar</td>
<td>6 (60.0)</td>
<td>2 (20.0)</td>
</tr>
<tr>
<td>Lower first molar</td>
<td>44 (71.0)</td>
<td>11 (17.7)</td>
</tr>
<tr>
<td>Lower second molar</td>
<td>7 (70.0)</td>
<td>1 (10.0)</td>
</tr>
<tr>
<td>Total</td>
<td>76 (69.7)</td>
<td>18 (16.5)</td>
</tr>
</tbody>
</table>

PR, Periapical radiography.

Statistics

Table II. Adequate and inadequate fill assessed by cone-beam computerized tomography (CBCT) by tooth type, n (%)

<table>
<thead>
<tr>
<th>Tooth type</th>
<th>Adequate fill assessed by both PR and CBCT</th>
<th>Underextension by CBCT (%)</th>
<th>Overextension by CBCT (%)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper first molar</td>
<td>19 (70.4)</td>
<td>4 (14.8)</td>
<td>4 (14.8)</td>
<td>27 (100)</td>
</tr>
<tr>
<td>Upper second molar</td>
<td>6 (60.0)</td>
<td>2 (20.0)</td>
<td>2 (20.0)</td>
<td>10 (100)</td>
</tr>
<tr>
<td>Lower first molar</td>
<td>44 (71.0)</td>
<td>11 (17.7)</td>
<td>7 (11.3)</td>
<td>62 (100)</td>
</tr>
<tr>
<td>Lower second molar</td>
<td>7 (70.0)</td>
<td>1 (10.0)</td>
<td>2 (20.0)</td>
<td>10 (100)</td>
</tr>
<tr>
<td>Total</td>
<td>76 (69.7)</td>
<td>18 (16.5)</td>
<td>15 (13.8)</td>
<td>109 (100)</td>
</tr>
</tbody>
</table>
studies on the level of termination of RCOs, we took the lead in developing criteria for CBCT to evaluate the endodontic obturation length and accordingly categorize the RCOs as adequate (flush) or inadequate (overextension or underextension). The establishment of evaluation standards of CBCT made it possible for clinicians to accurately diagnose the apical extension of RCOs in clinical practice. Nevertheless, the optimal obturation length is still controversial. As we know, besides anatomic and histologic factors, the outcome of root canal therapy is important for determining the optimal obturation length. Therefore, further follow-up studies on therapeutic outcome are needed to improve the evaluation system of the 2 imaging modalities for endodontic obturation length.

In the present investigation, RCOs terminating within 0-2 mm from the radiographic apex on the PR images were diagnosed by CBCT as overextension in 13.8% of the teeth and underextension in 16.5%. The percentage of overextension was slightly lower than that in ElAyouti et al.’s study,28 which reported that instrumentation beyond the apical foramen occurred in 22% (95% confidence interval 14%-30%) of the molars with radiographically acceptable working length. The discrepancy might be explained by the condition that combined electronic apex locator and PR was used to

Table III. Adequate and inadequate fill assessed by CBCT by root canal type, n (%)

<table>
<thead>
<tr>
<th>Jaw</th>
<th>Root canal type</th>
<th>Adequate fill assessed by both PR and CBCT</th>
<th>Adequate fill assessed by PR but inadequate fill assessed by CBCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxilla</td>
<td>Palatine</td>
<td>9 (75.0)</td>
<td>1 (8.3)</td>
</tr>
<tr>
<td></td>
<td>Mesiobuccal</td>
<td>8 (57.1)</td>
<td>4 (28.6)</td>
</tr>
<tr>
<td></td>
<td>Distobuccal</td>
<td>8 (72.7)</td>
<td>1 (9.1)</td>
</tr>
<tr>
<td>Mandible</td>
<td>Distal</td>
<td>20 (66.7)</td>
<td>3 (10.0)</td>
</tr>
<tr>
<td></td>
<td>Mesial</td>
<td>31 (73.8)</td>
<td>9 (21.4)</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>76 (69.7)</td>
<td>18 (16.5)</td>
</tr>
</tbody>
</table>

Abbreviations as in Table II.

Table IV. Adequate and inadequate fill assessed by CBCT according to different distances from RCO endpoint to radiographic Apex, n (%)

<table>
<thead>
<tr>
<th>Distance group</th>
<th>Adequate fill assessed by both PR and CBCT</th>
<th>Adequate fill assessed by PR but inadequate fill assessed by CBCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>10 (47.6)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Group 2</td>
<td>40 (88.9)</td>
<td>2 (4.4)</td>
</tr>
<tr>
<td>Group 3</td>
<td>16 (76.2)</td>
<td>5 (23.8)</td>
</tr>
<tr>
<td>Group 4</td>
<td>10 (45.5)</td>
<td>11 (50.0)</td>
</tr>
<tr>
<td>Total</td>
<td>76 (69.7)</td>
<td>18 (16.5)</td>
</tr>
</tbody>
</table>

Group 1: 0 to ≤0.5 mm; group 2: 0.5 to ≤1 mm; group 3: 1 to ≤1.5 mm; group 4: 1.5 to ≤2 mm.
Abbreviations as in Table II.

Table V. Adequate and inadequate fill assessed by CBCT according to the location of the root end of the RCO, n (%)

<table>
<thead>
<tr>
<th>Location class</th>
<th>Adequate fill assessed by both PR and CBCT</th>
<th>Adequate fill assessed by PR but inadequate fill assessed by CBCT</th>
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</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>50 (69.4)</td>
<td>15 (20.8)</td>
</tr>
<tr>
<td>Class 2</td>
<td>18 (81.8)</td>
<td>3 (13.6)</td>
</tr>
<tr>
<td>Class 3</td>
<td>8 (53.3)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Total</td>
<td>76 (69.7)</td>
<td>18 (16.5)</td>
</tr>
</tbody>
</table>

Class 1: central; class 2: distal or mesial; class 3: buccal or lingual.
Abbreviations as in Table II.
between these 2 methods. And ElAyouti et al. showed that electronic working length measurements with Root ZX reduced the percentage of overestimation with PRs. Nevertheless, the present study showed that, even though the exact measurement of working length was conducted combining these 2 methods, which is popular in current clinical practice, there were still parts of the radiographically acceptable RCOs that were evaluated by CBCT as inadequate.

The mesiobuccal root canals of the maxillary molars with radiographically acceptable RCOs apparently had a somewhat higher probability of inadequate extension than any other root canal of molars diagnosed by CBCT. This is in accordance with the considerable variation in root canal anatomy and the technical difficulties in instrumenting and obturating these canals. Caution may be needed in evaluating the obturation length of mesiobuccal root canals using traditional 2D radiographs.

The present survey has shown that when the distance from the end of the filling to the radiographic apex measured 0.5-1 mm on the PR image, the most RCOs were diagnosed as adequate by both PR and CBCT. Statistical analyses showed that the concordance rate between the 2 imaging modalities in the group with 0.5-1 mm distance was significantly higher than those with 0-0.5 mm and 1.5-2 mm distances. Many anatomic studies support this result. For example: The distance between the apical foramen and the anatomic apex averages ~0.59 mm; a scanning electron microscope study of teeth apices showed that the mean value of the distance from the apical foramen to the anatomic apex does not exceed 1 mm; the mean distance between the apical constriction and the anatomic apex is 0.89 mm; and root canal treatment should stop 1 mm from the radiographic apex. These results suggest that when the RCO radiographically terminates 0.5-1 mm short of the apex, the evaluation rated adequate for obturation length is comparatively reliable.

As a 3D imaging modality, CBCT provides more information about RCOs than does 2D imaging modality (PR). Besides apical extension of the fillings, the location of the fillings’ termini can also be diagnosed by CBCT. In the present study, the RCOs diagnosed by CBCT as terminating at the facial or lingual side of the root appeared to have a higher probability of disagreement between PR and CBCT for evaluating the length of obturations than those at the mesial, distal, or central side. For the former RCOs, overextension was the main diagnostic result by CBCT in the discordant evaluation with PR. These results are in agreement with the properties of PR: Because PR can render only a 2D image, the clinical radiograph of a root filling, of necessity taken in a buccolingual direction, will lead to superimposition of the buccal and lingual images. This limitation of conventional radiography may result in a clinical error in evaluation. These results validate the potentiality of CBCT in accurately evaluating the length of endodontic obturations.

In this study, we focused on informing dentists about the discordant and discordant evaluation of obturation length between PR and CBCT in vivo. The absolute accuracy of either imaging modality was not addressed, because of the lack of a criterion standard. Anatomic dissection may serve as a criterion standard for evaluating obturation length, but it is not feasible in a clinical situation. Future studies should address and compare the accuracy of the 2 imaging modalities to a criterion standard in vitro.

In conclusion, the results of this study showed that 30.3% of radiographically acceptable RCOs were evaluated by CBCT as inadequate. When the RCOs radiographically terminated 0.5-1 mm short of the apex, the evaluation rated as adequate for obturation length was comparatively reliable. As a potential 3D imaging modality for evaluating obturation length, the accuracy of CBCT needs further study.

REFERENCES

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