The detection of periapical pathosis using digital periapical radiography and cone beam computed tomography – Part 2: a 1-year post-treatment follow-up

S. Patel1,2, R. Wilson3, A. Dawood2, F. Foschi1 & F. Mannocci1

1Department of Conservative Dentistry, King’s College London Dental Institute, London; 2Private Practice Wimpole Street, London; and 3Department of Periodontology, King’s College London Dental Institute, London, UK

Abstract

Aim Part 2 of this clinical study aims to compare the radiographic change in periapical status of individual roots determined using digital periapical radiographs versus cone beam computed tomography (CBCT) 1 year after primary root canal treatment and to determine the radiological outcome of treatment for each tooth.

Methodology Periapical radiographs and CBCT scans of 123 teeth in 99 patients assessed 1 year after completion of primary root canal treatment by a single operator were compared with their respective pre-treatment (diagnostic) periapical radiographs and CBCT scans. The presence or absence as well as the increase or decrease in size of existing periapical radiolucency was assessed by a consensus panel consisting of two calibrated examiners. The panel viewed the images under standardized conditions. Paired comparison of the outcome diagnosis of individual roots and teeth was performed using generalized McNemar’s or Stuart–Maxwell test of symmetry analysis.

Results The ‘healed’ rate (absence of periapical radiolucency) was included (P < 0.001). A statistically significant difference in outcome diagnosis of single roots was observed between DPA and CBCT in single-rooted teeth and the buccal or mesio-buccal roots of multi-rooted teeth (P < 0.05). Analysis by tooth revealed that the ‘healed’ rate (absence of periapical radiolucency) was 87% using periapical radiographs and 73.9% using CBCT (P < 0.001). This increased to 95.1% and 84.7%, respectively, when the ‘healing’ group (reduced size of periapical radiolucency) was included (P < 0.002). Outcome diagnosis of teeth showed a statistically significant difference between systems (P < 0.001). Reconstructed CBCT images revealed more failures (17.6%) in teeth with no pre-operative periapical radiolucencies compared with periapical radiographs (1.3%) (P = 0.031). In teeth with existing pre-operative periapical radiolucencies, reconstructed CBCT images also showed more failures (13.9%) compared with periapical radiographs (10.4%).

Conclusion Diagnosis using CBCT revealed a lower healed and healing rate for primary root canal treatment than periapical radiographs, particularly in roots of molars. There was a 14 times increase in failure rate when teeth with no pre-operative periapical radiolucencies were assessed with CBCT compared with periapical radiographs at 1 year.

Keywords: cone beam computed tomography, outcome of endodontic treatment, periapical intraoral radiographs.

Received 14 August 2011; accepted 12 April 2012

Correspondence: Shanon Patel, 45 Wimpole Street, London W1G 8SB, UK (e-mail: shanonpatel@gmail.com).
Introduction

The diagnostic outcome of root canal treatment is based on clinical and radiological findings (Friedman et al. 2003, Ng et al. 2011). It is not uncommon for disease to be clinically asymptomatic (Kirkveang & Hørsted-Bindlev 2002, Huumenon & Ørstavik 2002, Wu et al. 2009); therefore, radiological assessment is essential to objectively determine the outcome of treatment. The results from diagnostic outcome studies allow the clinician to estimate the prognosis of the proposed root canal treatment. This can then be compared with the prognosis of possible alternative treatment strategies (for example, single-implant crown restorations); this essential information along with the benefits and risks of the various treatment options allows the patient to choose the most suitable treatment option for their individual needs (Friedman et al. 2003).

Periapical radiography is the technique of choice for diagnosing, managing and assessing endodontic disease (Patel et al. 2009a). Periapical periodontitis represents a reduction in the mineral density of the affected periapical bone in response to a localized inflammatory reaction to residual and/or re-infection within the root canal system (Bender 1982, Ørstavik & Larheim 2008); radiographically, this presents as a radiolucency. Conversely, the absence of a periapical radiolucency at the periapex of the root canal-treated roots indicates the absence of periapical periodontitis, suggesting that root canal treatment has been successful (Strindberg 1956, European Society of Endodontology 2006). This is the basis of how both non-surgical and surgical root canal treatments have been assessed for nearly 90 years (Blayney 1922, Peters & Wesselink 2002, Friedman et al. 2003, Chong et al. 2003, de Chevigny et al. 2008).

Ex vivo and in vivo studies have confirmed that periapical radiography is of limited use for detecting periapical radiolucencies (Bender & Seltzer 1961, Bender 1997, Jorge et al. 2008, Paula-Silva et al. 2009a). Small or early periapical lesions confined to the cancellous bone are not easily seen on radiographs, owing to the overlying cortical plate masking the periapical lesion; this phenomenon is known as ‘anatomical noise’ (Revesz et al. 1974, Gröndahl & Huumenon 2004). Periapical radiolucent lesions are usually only diagnosed when there has been perforation or erosion of the overlying cortical plate (Bender & Seltzer 1961, Jorge et al. 2008, Patel et al. 2009b). Further limitations include the compression of the complex three-dimensional anatomy of the area being radiographed into a two-dimensional shadowgraph and geometric distortion. These limitations mean that radiographs cannot consistently reveal the true nature and location of presence or absence of apical periodontitis (Van Vorde & Bjorndahl 1969, Forsberg & Halse 1994, Velvart et al. 2001, Paula-Silva et al. 2009a).

Several studies have been published confirming the improved diagnostic accuracy of cone beam computed tomography (CBCT) over conventional radiography for diagnosing periapical periodontitis (Löfgård-Hansen et al. 2007, Low et al. 2008, Estrela et al. 2008, Bornstein et al. 2011). Recently, Paula-Silva et al. (2009b) assessed the diagnostic outcome of root canal treatment performed in dogs using periapical radiographs and CBCT, they concluded that the treatment outcome varied according to the radiological system used; a favourable outcome was 79% and 35% with periapical radiographs and CBCT, respectively (Paula-Silva et al. 2009b). Small field of view scans are best suited for diagnosing and managing of endodontic problems (Patel 2009). To date, there have been no published studies comparing the diagnostic outcome of root canal treatment in humans using pre-diagnostic and follow-up radiographs.

The purpose the second part of this study was to determine the radiographic change in periapical status of individual roots using periapical radiographs and CBCT at 1 year after primary root canal treatment and to determine a radiological outcome of treatment for each tooth.

Materials and methods

Subject material

The subject material has been described in part 1 of this study (Patel et al. 2012). Diagnostic digital periapical radiographs and CBCT scans of teeth treatment planned for primary root canal treatment were taken of 151 teeth in 132 patients. The patients were then reviewed 1 year post-operatively (see later). Only patients whose teeth fulfilled the inclusion criteria were asked to participate in the study (Patel et al. 2012). Approval was sought and granted by the Guy’s Research Ethics Committee, Guy’s and St. Thomas Hospital National Health Service Trust (National Research Ethics Service, England) for this study.

Radiographic technique

The 1-year follow-up assessment included exposure of digital periapical radiographs and CBCT scans as described in part 1 of this study (Patel et al. 2012).
Primary root canal treatment procedure

All primary root canal treatments were carried out by a single operator in a single visit. The tooth to be treated was anaesthetized and isolated under rubber dam. Before starting primary root canal treatment, plaque deposits, calculus, caries and existing restorations were removed after which the restorability of the underlying tooth structure was assessed. In instances where minimal tooth structure was left, the tooth was restored with a glass ionomer foundation (Fuji IX glass ionomer cement; GC America, Alsip, IL, USA) to allow isolation with rubber dam.

All primary root canal treatments were performed using sterilized, single use endodontic files. A standardized protocol was used to disinfect and fill the root canal system. Each canal was initially negotiated with size 08 and 10 stainless steel Flexofiles® (Dentsply Maillefer, Ballaigues, Switzerland). The balanced force instrumentation technique was used to negotiate each canal to its provisional working length. The definitive working length was determined with the aid of an apex locator (Root ZX II®; J Morita, Kyoto, Japan) in conjunction with measurements using the CBCT software (I-Dixel®; J Morita). The working length was always 1 mm short of the ‘0’ apex locator reading length. Canals were then prepared to at least a size 20 Flexofile® to the working length, after which ProTaper® nickel-titanium rotary instruments (Dentsply Maillefer) at 300 RPM were used in a crown-down approach to prepare each root canal to at least a F1 master apical rotary file. Canals were continuously irrigated with 2% sodium hypochlorite (Chloraxid® 2.0%; PPH Cerkamed, Sandomierska, Poland) for 30 min, the irrigant was replenished every 3–4 min after which it was immediately agitated with an appropriately selected gutta-percha point extending to 2 mm short of the working length for approximately 30 s. The root canals were then irrigated with 15% ethylenediaminetetraacetic acid (EDTA) (ENDO-Solution®; PPH Cerkamed) followed by a final irrigation with sodium hypochlorite. The irrigant was ultrasonically energized with a size 25 Endo-activator® (Denstply Maillefer) for 1 min. The canals were then dried with paper points and filled with gutta-percha and AH sealer (Denstply Maillefer) using a warm vertical compaction technique. The teeth were then restored with permanent glass ionomer cores (Fuji IX® glass ionomer cement) or composite resin (Herculite ultra®; Kerr corporation, Orange, CA, USA) depending on the referring practitioner’s preference.

A dental operating microscope was used during treatment, and all teeth requiring permanent, cuspal-coverage restorations were restored by the referring practitioner within 1 month of completion of the root canal treatment.

Follow-up assessment

All patients were contacted approximately 11 months later to schedule a 12-month review appointment with the first author. Clinical assessment included tenderness to percussion, mobility and checking for increased periodontal probing depths. The soft tissues were also assessed for tenderness to palpation, signs of erythema and sinuses; the integrity and marginal fit of the definitive restoration were also assessed. Periapical radiographs and CBCT radiographic assessment was carried out as described previously in part 1 of this study (Patel et al. 2012).

Radiological assessment

Calibration of examiners

Assessment of the data was carried out by a consensus panel that consisted of the same 2 endodontists described in part 1 of this study (Patel et al. 2012). The first author was not involved in the assessment of the radiographic images. Both members of the consensus panel were not aware of the purpose of the study. As several months had elapsed between the assessment of radiographic images in part 1 and part 2 of this study, the examiners were retrained using 50 examples of periapical radiographs and CBCT reconstructed images with and without the presence of periapical radiolucencies before embarking on the assessment. Before assessing the experimental material, the inter-examiner agreement of the consensus panel members was assessed by asking them to grade the outcome of root canal treatment of 20 cases using periapical radiographs and reconstructed CBCT images. These cases were not part of the experimental material. The radiographs and CBCT data sets were viewed as Keynote® presentations (Apple, Cupertino, CA, USA) on laptop computers (MacBook Pro®; Apple Computer Inc.) with 15.5-inch Light-emitting diode (LED) backlit screen with a pixel resolution of 1680 × 1050.

The radiographic diagnostic outcome of each root was classified into six categories:

1. New periapical radiolucency;
2. Enlarged periapical radiolucency;
3. Unchanged periapical radiolucency;
4. New periapical radiolucency;
5. Enlarged periapical radiolucency;
6. Unchanged periapical radiolucency;
7. New periapical radiolucency;
8. Enlarged periapical radiolucency;
9. Unchanged periapical radiolucency;
10. New periapical radiolucency;
11. Enlarged periapical radiolucency;
12. Unchanged periapical radiolucency;
13. New periapical radiolucency;
14. Enlarged periapical radiolucency;
15. Unchanged periapical radiolucency;
16. New periapical radiolucency;
17. Enlarged periapical radiolucency;
18. Unchanged periapical radiolucency;
19. New periapical radiolucency;
20. Enlarged periapical radiolucency;
21. Unchanged periapical radiolucency;
22. New periapical radiolucency;
23. Enlarged periapical radiolucency;
24. Unchanged periapical radiolucency;
25. New periapical radiolucency;
26. Enlarged periapical radiolucency;
27. Unchanged periapical radiolucency;
28. New periapical radiolucency;
29. Enlarged periapical radiolucency;
30. Unchanged periapical radiolucency;
4. Reduced periapical radiolucency;
5. Resolved periapical radiolucency;
6. Unchanged healthy periapical status (no radiolucency before and after treatment).

For the purposes of clinically defined outcomes, a ‘healed’ outcome (i.e. strict criterion) was defined where a periapical radiolucency was absent (outcome 5 and 6) and a ‘healing’ outcome (i.e. loose criterion) where a radiolucency had reduced in size or was absent (outcome 4–6).

In multi-rooted teeth, the diagnostic outcome for the tooth was assessed using the root with the ‘worst’ diagnostic outcome category, whilst for single-rooted teeth the diagnostic outcome category for the root was also used for tooth outcome. In the event of multi-rooted teeth with the periapical status of one root classified as ‘category 1’ and the other root classified as ‘category 2’, the category 1 was considered the ‘worst case’ scenario.

An Excel® (Excel 2010; Microsoft, Richmond, WA, USA) spreadsheet was created to log data. All data were anonymized. A series of up to 10 CBCT reconstructed images that best confirmed the presence or absence of a radiolucent periapical radiolucency(s) in the sagittal, coronal and/or axial planes was used as the starting point for each tooth observation. The consensus panel also had access to the raw CBCT tooth outcome is 5 and 4, respectively.

Figure 1 (a) pre-operative radiograph of 26 revealing periapical radiolucencies on mesio-buccal and palatal root. (b) 1-year follow-up radiograph reveals a significant reduction in size of the periapical radiolucency on the mesio-buccal root (outcome 4), complete resolution of periapical radiolucency on the palatal root (outcome 5), and no change in the healthy periapical status of the distobuccal root (outcome 6). (c–h) reformatted cone beam computed tomography (CBCT) images reveal pre-operative periapical radiolucencies on mesio-buccal, disto-buccal and palatal roots, which 1 year later have reduced in size on the mesio-buccal and disto-buccal roots (outcome 4), and has resolved (outcome 5) on the palatal root. Radiographic and CBCT tooth outcome is 5 and 4, respectively.
CBCT data using CBCT software (one-Volume viewer, Morita) allowing them to scroll through any of the orthogonal scans. All images were assessed in a quiet dimly lit room. All CBCT data sets were assessed using the same computer monitor(s).

Assessment of experimental data
The experimental material was assessed jointly by both examiners. The radiographic images were then assessed in three sessions as follows:

In the first session, the consensus panel assessed 50% of the periapical radiographs \( (n = 61) \) followed by 50% of CBCT reconstructed images \( (n = 62) \); in the second session, the consensus panel assessed the remaining 50% of CBCT reconstructed images \( (n = 61) \) followed by the remaining 50% of periapical radiographs \( (n = 62) \). Periapical radiographs and CBCT images of the same tooth were not assessed in the same session; in the third session, 70 periapical radiographs and 70 series of CBCT images were assessed to determine intra-consensus panel agreement.

---

**Figure 2** (a) pre-operative radiograph of 36, and (b) 1-year follow-up radiograph revealing healthy periapical tissues for both roots (outcome 6), (c–d) reformatted cone beam computed tomography (CBCT) images reveal no pre-operative periapical radiolucencies on either the mesial or distal roots, but 1 year later, there are new periapical radiolucencies on both roots (outcome 1). Radiographic and CBCT tooth outcome is 6 and 1, respectively.

**Figure 3** (a) pre-operative radiograph of 37 and, (b) 1-year follow-up radiograph revealing healthy periapical tissues (outcome 6 for both roots). (c–d) reformatted cone beam computed tomography (CBCT) images reveal the no pre-operative periapical radiolucencies on either the mesial or distal roots, and 1 year later, the periapical radiolucencies are still within normal limits (outcome 6). Radiographic and CBCT tooth outcome is 6.
The radiographic images were assessed as described in the calibration session (Table 1). There was at least a 1-week interval between each session, and the images within each session were randomly ordered. The preoperative and the 1-year follow-up periapical radiographs of each case were viewed together to allow the examiners to assess the images for the presence, absence or change (increase/decrease) in size of an existing periapical radiolucency (Figs 1–4). This was also done when the CBCT reconstructed images were assessed. The first and second sessions were divided into at least two separate viewing periods over the course of a day to minimize the likelihood of consensus panel fatigue. The periapical tissue status category 5 and 6 were given when there was an intact lamina dura with a maximum widening of 2 mm immediately adjacent to any flush or extruded root filling material.

Data analysis

Data were analysed using Stata™ software (Stata 11, College Station, TX, USA). Kappa analysis was used to assess the inter-examiner agreement prior to the main study and the intra-consensus panel agreement during the study (Tables 2 & 3). Comparison of periapical radiographs with reconstructed CBCT images for diagnosis of outcome by individual roots and by tooth was performed using the generalized McNemar’s or Stuart–Maxwell test of symmetry for testing marginal homogeneity with multiple paired categories.

Comparison of diagnostic outcome by tooth type within and between radiographic systems was performed using chi-square tests. Anterior teeth included incisors and canines and posterior teeth included premolar and molar teeth. Where multiple contrasts were performed on the same data set, as with the comparison of anterior/posterior and maxillary/mandibular sites, the $P$ value for statistical significance was adjusted ($P < 0.01$). Otherwise, $P < 0.05$ was accepted as indicating statistical significance.

Results

Ninety-nine of the original 132 patients from part 1 of this study were reviewed (75% recall rate), this included 123 teeth (Figure 5) of the original 151 teeth initially treated (82%). The percentage of women and men was 58% and 42%, respectively. The mean age of the patients was 44.5 years (SD 13.7) and ranged from 9 to 76 years of age.

Clinical assessment

None of the patients presented with any symptoms at 1 year post-treatment, and they all confirmed that they were not avoiding masticating with the root canal-treated tooth (i.e. the root canal-treated tooth was functional). Clinical examination of all the teeth and the surrounding tissues was unremarkable, and all coronal restorations were intact.

Figure 4 (a) pre-operative radiograph of 24 revealing periapical radiolucencies on the buccal and palatal roots, (b) 1-year follow-up radiograph reveals complete resolution of periapical radiolucencies (outcome 5). (c–d) Reformatted cone beam computed tomography (CBCT) images reveal pre-operative periapical radiolucencies on the buccal and palatal roots, which 1 year later have completely resolved (outcome 5). Radiographic and CBCT tooth outcome is 5.
A statistically significant difference in outcome diagnosis of single roots was observed between periapical radiographs and CBCT in roots 1 and 2 (P < 0.001, respectively). The difference for root 3 did not reach statistical significance (P = 0.1) (Table 4 & 5). A statistically significant difference in outcome diagnosis of teeth was observed between periapical radiographs and CBCT (P < 0.001) (Table 6).

Teeth with no pre-treatment periapical radiolucencies (Table 7) showed significantly (P < 0.001) less failures (1.3%) with periapical radiographs compared with reconstructed CBCT images (17.6%). Table 7 shows the combined prevalence of enlarged and unchanged periapical radiolucencies was 10.4% for periapical radiographs and 13.9% for reconstructed CBCT images. This difference was not statistically significant (P = 0.8).

Comparison within both radiographic systems revealed statistically significant differences (chi-square analysis) in outcome diagnoses by tooth group for both periapical radiographs (P = 0.002) and CBCT reconstructed images (P = 0.01) (Table 8). However, two-group comparisons, with P values adjusted for multiple contrasts, showed few differences, indicating only that maxillary and mandibular posterior teeth both differed significantly from maxillary anterior teeth when diagnostic outcome was assessed by periapical radiographs; and maxillary posterior teeth differed significantly from mandibular anterior teeth when outcome was diagnosed using CBCT (P < 0.01).

Comparison between periapical radiographs and reconstructed CBCT images revealed a statistically significant difference (P = 0.002) in the number of occurrences of each diagnostic outcome for maxillary posterior teeth (Table 8). There was also a difference in outcome for mandibular anterior teeth between the two radiographic systems that approached statistical significance (P = 0.04). There was no difference in outcome for mandibular posterior (P = 0.1) and maxillary anterior (P = 0.7) teeth between periapical radiographs and CBCT reconstructed images.

**Discussion**

In this prospective clinical study, the radiographic diagnostic outcome of root canal treatment was assessed using periapical radiographs and recon-

---

**Figure 5** Frequency distribution of teeth (n = 123) assessed 1 year post-root canal treatment.

**Table 1** Numbering of roots observed and identified during assessment

<table>
<thead>
<tr>
<th>Tooth type</th>
<th>Root number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incisors, canines, premolars&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Single root</td>
</tr>
<tr>
<td>Premolars&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Buccal</td>
</tr>
<tr>
<td>Mandibular molars</td>
<td>Buccal</td>
</tr>
<tr>
<td>Maxillary molars</td>
<td>Buccal</td>
</tr>
</tbody>
</table>

<sup>a</sup>Premolar with a single root canal.

<sup>b</sup>Premolar with two root canals.

---

**Table 2** Kappa values (95% confidence intervals) for pre-study inter-examiner agreement on outcome diagnosis using periapical radiography (DPA) and cone beam computed tomography (CBCT) (n = 20)

<table>
<thead>
<tr>
<th>System</th>
<th>Root 1</th>
<th>Root 2</th>
<th>Root 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPA</td>
<td>0.837 (0.813–0.919)</td>
<td>0.440 (0.155–1.000)</td>
<td>–&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>CBCT</td>
<td>1.000 (1.000–1.000)</td>
<td>0.726 (0.634–1.000)</td>
<td>0.588 (0.093–1.000)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Too few values for analysis.
CBCT images. To the author’s knowledge, this is the first published prospective, longitudinal clinical study in humans comparing endodontic treatment outcome using both radiographic techniques before treatment and at a 1-year review. A recent retrospective clinical study assessed endodontic outcome with periapical radiographs and reconstructed CBCT images but no pre-treatment CBCTs were taken (Liang et al. 2011).

An important aspect that has to be addressed is the potential presence of false readings in the reconstructed CBCT images. It would have been unethical to undertake a histologic assessment of the patient’s periapical tissues, and it was not possible owing to cross-infection control regulations, to undertake a similar study on cadavers. However, a study on the diagnostic accuracy of small volume CBCT and periapical radiographs for the

---

### Table 3

Kappa values (95% confidence intervals) for intra-consensus panel agreement on outcome diagnosis using periapical radiographs (DPA) and cone beam computed tomography (CBCT) 1 week apart (n = 70)

<table>
<thead>
<tr>
<th>System</th>
<th>Root 1</th>
<th>Root 2</th>
<th>Root 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DPA</td>
<td>CBCT</td>
<td>DPA</td>
</tr>
<tr>
<td></td>
<td>(0.651–0.886)</td>
<td>(0.736–0.856)</td>
<td>(0.776–0.857)</td>
</tr>
<tr>
<td>DPA</td>
<td>0.768</td>
<td>0.915</td>
<td>0.736</td>
</tr>
<tr>
<td>CBCT</td>
<td>(0.879–0.980)</td>
<td>(0.916–0.959)</td>
<td>0.858</td>
</tr>
</tbody>
</table>

---

### Table 4

Frequency distribution of each periapical outcome of endodontic treatment for paired roots assessed using periapical radiographs (DPA) and CBCT

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Root 1</th>
<th>Root 2</th>
<th>Root 3</th>
<th>Total 1 + 2 + 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – new lesion</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2 – enlarged lesion</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>3 – unchanged lesion</td>
<td>10</td>
<td>9</td>
<td>3</td>
<td>22</td>
</tr>
<tr>
<td>4 – reduced lesion</td>
<td>30</td>
<td>28</td>
<td>12</td>
<td>70</td>
</tr>
<tr>
<td>5 – resolved lesion</td>
<td>32</td>
<td>31</td>
<td>14</td>
<td>77</td>
</tr>
<tr>
<td>6 – no lesion before/after treatment</td>
<td>81</td>
<td>53</td>
<td>23</td>
<td>157</td>
</tr>
<tr>
<td>Total</td>
<td>123</td>
<td>123</td>
<td>70</td>
<td>218</td>
</tr>
</tbody>
</table>

---

### Table 5

Percentage of combined outcomes indicating healing, no change or failure for individual roots (data derived from Table 4) assessed with periapical radiographs (DPA) and CBCT

<table>
<thead>
<tr>
<th>Outcome categories</th>
<th>Root 1</th>
<th>Root 2</th>
<th>Root 3</th>
<th>Total 1 + 2 + 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2/3 – failed</td>
<td>3.3</td>
<td>13.8</td>
<td>1.4</td>
<td>18.5</td>
</tr>
<tr>
<td>1/2 – new/larger lesions</td>
<td>0</td>
<td>9.8</td>
<td>1.4</td>
<td>11.2</td>
</tr>
<tr>
<td>3 – no change in size</td>
<td>3.2</td>
<td>4.1</td>
<td>0</td>
<td>7.3</td>
</tr>
<tr>
<td>4/5/6 – healing (includes healed)</td>
<td>96.7</td>
<td>86.2</td>
<td>98.6</td>
<td>97.2</td>
</tr>
<tr>
<td>4 – healing</td>
<td>8.1</td>
<td>17.9</td>
<td>0</td>
<td>25.7</td>
</tr>
<tr>
<td>5 – healed</td>
<td>22.8</td>
<td>25.2</td>
<td>13.7</td>
<td>41.7</td>
</tr>
<tr>
<td>5/6 – healed</td>
<td>88.6</td>
<td>68.3</td>
<td>98.6</td>
<td>92.7</td>
</tr>
<tr>
<td>Total</td>
<td>123</td>
<td>123</td>
<td>70</td>
<td>218</td>
</tr>
</tbody>
</table>

---

### Table 6

Frequency distribution (percentage) of outcome of treatment for each tooth assessed using periapical radiographs (DPA) and cone beam computed tomography (CBCT)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>DPA</th>
<th>CBCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – new lesion</td>
<td>0.8</td>
<td>7.3</td>
</tr>
<tr>
<td>2 – enlarged lesion</td>
<td>1</td>
<td>5.1</td>
</tr>
<tr>
<td>3 – unchanged lesion</td>
<td>4</td>
<td>5.1</td>
</tr>
<tr>
<td>4 – reduced lesion</td>
<td>10</td>
<td>27</td>
</tr>
<tr>
<td>5 – resolved lesion</td>
<td>33</td>
<td>28.5</td>
</tr>
<tr>
<td>6 – no lesion before/after treatment</td>
<td>74</td>
<td>42</td>
</tr>
<tr>
<td>Total</td>
<td>123</td>
<td>123</td>
</tr>
</tbody>
</table>
Detection of artificially created periapical lesions on dry mandibles demonstrated that CBCT was far superior to periapical radiographs in terms of sensitivity (100% vs. 25%, respectively); however, both systems gave perfect results (100%) for specificity (Patel et al. 2009b), a finding confirmed by Paula-Silva et al. (2009c).

The 6-point classification used in the present study allowed the assessment of the nature of existing periapical lesions in more detail. The 1-year follow-up of patients in the present study conformed to quality guidelines for endodontic treatment (European Society of Endodontology 2006). The terms ‘effective’ and ‘ineffective’ root canal treatment have been suggested to replace ‘healed/healing’ and ‘failure’, respectively (Wu et al. 2011a,b). This terminology may be a more pragmatic approach to assess (and manage) the outcome of root canal treatment.

The study is ongoing and patients will continue to be recalled on a periodic basis and the data analysed. Although a higher recall at review would have been ideal, the 75% was acceptable. The patients who were contacted but declined a review appointment were all asked whether their root canal-treated tooth was symptomatic and whether they were actively using it; all reported no symptoms and confirmed that the tooth was functional. Patients who were not reviewed fell into one of two categories. First, those who declined a review appointment as they felt they could not justify and/or afford the time and/or indirect costs of attending. The second group consisted of patients who could not be contacted as they either did not return messages or had moved away without leaving forwarding contact details. The problems of recalling patients in clinical studies are well documented (Sprague et al. 2003, Ross et al. 2009). Reasons often cited for failing or the inability to attend review appointments include: expense (for example, transport), the transient nature of the working population in large cities and lack of time, including travelling to and from work/home (Friedman et al. 2003, Sprague et al. 2003, Ng et al. 2011).

As in part 1 of this study, when assessing multi-rooted teeth, the periapical status on each identifiable

**Table 7** Outcome of treatment for each tooth as a number (percentage) with periapical radiographs (DPA) and cone beam computed tomography (CBCT) of teeth with (a) no pre-operative peri-apical radiolucency, (P < 0.001 chi-square test) (b) existing peri-apical radiolucency, (P = 0.759 chi-square test)

<table>
<thead>
<tr>
<th>Outcome category</th>
<th>DPA</th>
<th>CBCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Teeth with new lesions (outcome 1)</td>
<td>1 (1.3)</td>
<td>9 (17.6)</td>
</tr>
<tr>
<td>Teeth with no new lesions (outcome 6)</td>
<td>74 (96.7)</td>
<td>42 (82.4)</td>
</tr>
<tr>
<td>Total number of teeth showing no pre-operative radiolucency</td>
<td>75</td>
<td>51</td>
</tr>
<tr>
<td>(b) Teeth with reduced lesions (outcome 4 and 5)</td>
<td>43 (89.6)</td>
<td>62 (86.1)</td>
</tr>
<tr>
<td>Teeth with enlarged/unchanged lesions (outcome 2 and 3)</td>
<td>5 (10.4)</td>
<td>10 (13.9)</td>
</tr>
<tr>
<td>Total number of teeth showing pre-operative radiolucency</td>
<td>48</td>
<td>72</td>
</tr>
</tbody>
</table>

Outcome of each root was assessed using the following criteria: 1-new periapical lesion, 6-no periapical before or after treatment. With multi-root teeth, the ‘worst’ root determined the outcome.

Outcome of each root was assessed using the following criteria: 2-enlarged periapical lesion, 3-unchanged periapical lesion, 4-reduced periapical lesion, 5-resolved periapical lesion.

**Table 8** Frequency distribution (percentage) of outcome of endodontic treatment with periapical digital radiography (DPA) and cone beam computed tomography (CBCT) for maxillary posterior, mandibular posterior, maxillary anterior and mandibular anterior teeth

<table>
<thead>
<tr>
<th>Outcome category</th>
<th>Maxillary posterior</th>
<th>Mandibular posterior</th>
<th>Maxillary anterior</th>
<th>Mandibular anterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 (0.0)</td>
<td>9 (2.1)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>2</td>
<td>1 (0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>3</td>
<td>0 (0.0)</td>
<td>3 (6.4)</td>
<td>0 (0.0)</td>
<td>1 (11.1)</td>
</tr>
<tr>
<td>4</td>
<td>3 (6.5)</td>
<td>4 (8.5)</td>
<td>3 (14.3)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>5</td>
<td>10 (21.7)</td>
<td>9 (19.2)</td>
<td>12 (57.1)</td>
<td>2 (22.2)</td>
</tr>
<tr>
<td>6</td>
<td>32 (69.6)</td>
<td>30 (63.8)</td>
<td>6 (28.6)</td>
<td>6 (66.7)</td>
</tr>
<tr>
<td>Total</td>
<td>46 (100)</td>
<td>47 (100)</td>
<td>21 (100)</td>
<td>9 (100)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outcome category</th>
<th>Maxillary posterior</th>
<th>Mandibular posterior</th>
<th>Maxillary anterior</th>
<th>Mandibular anterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 (6.5)</td>
<td>6 (12.8)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>2</td>
<td>2 (4.4)</td>
<td>2 (4.3)</td>
<td>0 (0.0)</td>
<td>1 (11.1)</td>
</tr>
<tr>
<td>3</td>
<td>3 (6.5)</td>
<td>2 (4.3)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>4</td>
<td>14 (30.4)</td>
<td>8 (17.0)</td>
<td>5 (23.8)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>5</td>
<td>5 (10.9)</td>
<td>13 (27.7)</td>
<td>10 (47.6)</td>
<td>7 (77.8)</td>
</tr>
<tr>
<td>6</td>
<td>19 (41.3)</td>
<td>16 (34.0)</td>
<td>6 (28.6)</td>
<td>1 (11.1)</td>
</tr>
<tr>
<td>Total</td>
<td>46 (100)</td>
<td>47 (100)</td>
<td>21 (100)</td>
<td>9 (100)</td>
</tr>
</tbody>
</table>

Outcome was assessed using the following criteria: 1-new lesion, 2-enlarged lesion, 3-unchanged lesion, 4-reduced lesion, 5-resolved lesion, 6-no lesion before or after treatment.
root was noted, thus allowing the outcome of matching pairs of roots using periapical radiographs and CBCT reconstructed images to be assessed (Patel et al. 2012).

A single periapical radiograph was assessed for each tooth, this is similar to other published work assessing outcome of root canal treatment (Friedman et al. 2003, de Chevigny et al. 2008). This was also consistent with the assessment of the periapical status before treatment commenced in part 1 of this paper (Patel et al. 2012). In the present study, the increased or decreased size of a periapical radiolucency at the 1-year follow-up was compared with any pre-treatment radiolucency. This type of visual comparison has been used in the majority of outcome studies (de Chevigny et al. 2008, Ng et al. 2011). Recently, volumetric assessment of periapical radiolucencies visualized on CBCT images has been carried out (Paula-Silva et al. 2009a). However, the accuracy of these in vivo volumetric measurements of periapical radiolucencies has not been confirmed.

The consensus panel agreement was acceptable: at least where sufficient roots were presented for diagnosis, the low Kappa value for root 3 was owing to the small sample size. However, agreement for the intra-consensus panel assessment, which was used in the main study, was excellent. The examiners were both experienced in the use of CBCT for managing endodontic problems including detecting radiographic signs of periapical periodontitis. Both radiographic techniques were standardized as were the viewing sessions; therefore, minimizing the overall observer variation owing to faults in radiographic technique, knowledge and judgment (Robinson et al. 2005, Brealey & Westwood 2007). As would be expected, inter-examiner agreement with CBCT was higher than for periapical radiographs, confirming its superior reliability. This is in agreement with the results reported by other studies assessing periapical radiolucencies (Sogur et al. 2009, Lennon et al. 2011, Liang et al. 2011). The intra-consensus panel agreement also followed a similar trend of being higher with CBCT (0.858–0.915) compared with periapical radiographs (0.736–0.776). These levels of agreement were excellent (Landis & Koch 1977). Anatomical noise and the compression of three-dimensional anatomical structures were probably the major contributory factors that resulted in the poorer kappa scores with periapical radiographs. Ideally, having more examiners would have made the present study stronger. However, it would have been very difficult to recruit more examiners who would have been willing to assess over 1000 reconstructed CBCT images and data sets. Previous prospective endodontic outcome studies have also used one or two examiners (Friedman et al. 2003, Ng et al. 2011).

Several investigations have shown that inter-examiner agreement can be as little as 25% between examiners (Tewary et al. 2011) and one ‘outlier examiner’ can skew results (Goldman et al. 1972, Tewary et al. 2011). As with part 1 of this study, viewing sessions were kept as short as practically possible to reduce the likelihood of examiner fatigue.

The prevalence of unresolved periapical radiolucency after primary root canal treatment was significantly higher when teeth were assessed with CBCT compared with periapical radiographs regardless of whether the data were assessed by individual roots or by tooth. Previous studies, using periapical radiographs alone, have concluded that diagnostic outcome results were similar regardless of whether outcome was assessed as ‘tooth’ or ‘root’ units (Hoskinson et al. 2002, Ng et al. 2011); a similar conclusion was also reached in this study.

More roots appeared not to have changed from their pre-treatment healthy periapical status (outcome 6) with periapical radiographs (75.2%) compared with CBCT (50.9%), that is, they retained their healthy pre-treatment periapical status.

Fourteen times more new periapical radiolucencies (outcome 1) were detected with CBCT compared with periapical radiographs in teeth for outcome 1, this may be partially explained by the fact that new periapical radiolucencies are clearly very small in size and more easily detected by the most sensitive technique.

Interestingly, these teeth were all molars, and only 1 was associated with sealer extrusion, this suggests that foreign body reactions were not associated with the presence of radiolucencies in teeth that did not show any periapical radiolucency pre-operatively and that the technical challenges associated with the treatment of molars might have reduced the success rate in these teeth. It is possible that these radiolucencies are transient; the aim is to review all these teeth at 2, 3 and 4 years post-treatment which will provide a better understanding of the long-term dynamics of periapical healing. The prevalence of failure of primary root canal treatment in teeth with pre-treatment periapical radiolucencies (outcome 2 and 3) was higher with CBCT (13.9%) compared with periapical radiographs (10.4%).

The results from the periapical radiographs assessment in the present study is in agreement with the literature (Friedman et al. 2003, de Chevigny et al. 2008, Ng et al. 2008) that associates the absence of a
pre-operative periapical radiolucency with a higher success rate of primary root canal treatment.

Teeth with no pre-operative periapical radiolucency can be either teeth presenting with a carious exposures, irreversible pulpitis and virtually no infection within the root canal space or teeth with a root canal infection that is not sufficient to provoke an inflammatory reaction of the periapical tissues (Ricucci et al. 2009). All nine teeth with failed root canal treatment in outcome ‘outcome 1’ had vital pulp tissue. It is unlikely that endodontic treatment was unable to remove the few bacteria that might have been present within the root canal space of these vital and/or necrotic cases. It is possible that bacteria are introduced into the root canal space during the root canal treatment itself despite the use of rubber dam, sterile instruments and the adherence of strict aseptic practices. Niazi et al. (2010) demonstrated that nosocomial infections from bacteria such as Propionibacterium acnes and Staphylococcus epidermidis are likely to be associated with failures of root canal treatments.

There is a considerable body of evidence highlighting the increased accuracy of CBCT compared with periapical radiographs (Patel et al. 2009b, Paula-Silva et al. 2009b,c). All these studies compared the radiographic findings of periapical radiographs and reconstructed CBCT images to a reference standard and all concluded that CBCT had a higher degree of diagnostic accuracy compared with periapical radiographs for detecting periapical radiolucencies. The lower prevalence of pre-operative periapical radiolucency detected by periapical radiography was most probably due to anatomical noise masking existing periapical radiolucencies (Paula-Silva et al. 2009b, Patel et al. 2009a). The reason for this improved diagnostic accuracy is principally because CBCT software creates reconstructed images from slices of data in any plane and location of the region of interest, thus eliminating lack of three-dimensional assessment and anatomical noise which hampers the accuracy of periapical radiography. This results in a higher signal-to-noise ratio and image contrast, thus improving the detection of periapical radiolucencies (Bender 1997, Soğur et al. 2009). In addition, unlike periapical radiographs that are susceptible to geometric distortion, the CBCT reconstructed images have been shown to be a very accurate representation of the region of interest (Murmulla et al. 2005, Ludlow et al. 2007, Mischkowski et al. 2007, Stratemann et al. 2008).

Well-designed prospective clinical studies are essential to determine the diagnostic outcome of root canal treatment. The results from these studies allow us to estimate the prognosis of various treatments, thus greatly assisting the patient to make an educated informed decision on the best treatment option for their unique endodontic problem (Friedman et al. 2003, Wu et al. 2009).

The increased accuracy of CBCT may reveal periapical radiolucencies that may otherwise go undetected when assessed with conventional two dimensional radiographs. Such information may reveal different outcome predictors for endodontic treatment and also give more of an insight into the healing dynamics of periapical periodontitis (Wu et al. 2011a,b). For example, perhaps CBCT should be considered when comparing different treatment strategies (single versus multiple visit endodontic treatment, or different preparation and/or instrumentation techniques); the increased accuracy of CBCT may highlight clinically relevant differences that may otherwise not be detected with radiographs (Ng et al. 2011).

Conclusion

Diagnosis using CBCT revealed a lower healed and healing rate for primary root canal treatment than periapical radiographs. Molar teeth with no pre-operative periapical radiolucency revealed a fourteenfold higher failure rate when assessed using CBCT (17.6%) compared with periapical radiographs (1.3%).

References


