Dentomaxillofacial Radiology (2017) 46, 20160463

birpublications.org/dmfr

RESEARCH ARTICLE

Comparing cone-beam computed tomography with periapical radiography for assessing root canal obturation *in vivo* using microsurgical findings as validation

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Objectives: The aim of this study was to verify whether there is a difference in the *in vivo* performance characteristics of CBCT and periapical radiography (PR) in assessing the apical extension of root canal obturation (RCO) and to evaluate the ability of CBCT in void detection using microsurgical findings as validation.

Methods: This study included 323 tooth roots that required surgical treatment and for which pre-existing periapical radiographs and CBCT images were available. Three calibrated observers individually analyzed the periapical radiographs, CBCT images and photomicrographs of each root. Performance characteristics of CBCT and PR were compared in terms of their evaluation of the apical extension of the RCOs. The ability of CBCT to detect voids in the RCOs was evaluated using microsurgical findings as validation. Kappa values were used for intraobserver/interobserver agreement.

Results: Perfect intraobserver/interobserver agreement (1.0) was achieved when using photomicrography. The two agreements of PR were superior to those of CBCT when CBCT was used to detect voids ($p < 0.05$). The sensitivity of CBCT [0.86, 95% confidence interval (CI) 0.76–0.93] was superior to that of PR (0.66, 95% CI 0.54–0.76) in detecting overextension ($p < 0.005$). CBCT showed a poor sensitivity (0.24, 95% CI 0.19–0.30) and specificity (0.67, 95% CI 0.54–0.78) in void detection.

Conclusions: CBCT was better than PR for evaluating the apical extension of RCOs. CBCT, with its poor sensitivity and specificity, might both overestimate and underestimate the proportion of voids in RCOs. CBCT was not suitable for evaluating the quality of RCOs.

Dentomaxillofacial Radiology (2017) **46**, 20160463. doi: 10.1259/dmfr.20160463

Cite this article as: Song D, Zhang L, Zhou W, Zheng Q, Duan X, Zhou X, et al. Comparing cone-beam computed tomography with periapical radiography for assessing root canal obturation *in vivo* using microsurgical findings as validation. *Dentomaxillofac Radiol* 2017; **46**: 20160463.

Introduction

A major goal in root canal therapy is to minimize the occurrence of root or periapical infection. Successful microorganism control depends on many factors, including cavity access, root canal preparation, irrigation and obturation.[1] The apical third of the root canal has a complex anatomical structure, which might complicate the endodontic treatment.[2,3] As a consequence of this structure, complete obturation of the apical third of a root may be difficult to achieve.

The quality of root fillings is usually assessed in radiographs. The most commonly used radiographic methods are periapical radiography (PR) and digital

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Received 3 December 2016; revised 17 February 2017; accepted 20 February 2017

radiographs,[3,4] the benefits and defects of which should be recognized. These methods provide a two-dimensional image of a three-dimensional (3D) structure;[5] consequently, they might miss buccal–lingual information. Overextension may be missed when the apical extension of root canal obturation (RCO) does not exceed the radiologic apex because of the diversity of the major apical foramen position.[6,7]

CBCT is a 3D imaging method that provides the possibility of viewing a specific tooth or teeth in any view. CBCT is increasingly being used in dentistry, in the fields of oral surgery, endodontics and orthodontics.[8] Endodontic applications of CBCT include assessment of root canal anatomy, diagnosis of periapical pathosis or trauma, treatment planning and assessment of the outcome of root canal treatment.[8–10]

Previous studies have demonstrated that CBCT-based root canal length measurements have been shown to be accurate and reliable.[11–13] An *in vivo* clinical study showed that limited CBCT scans can be used for determining the endodontic working length.[12] As Santos et al[14] mentioned before, apical extension was the most critical parameter of quality in RCOs. However, few studies have focused on using CBCT to evaluate the apical extension of RCO. A recent *in vivo* study has showed that CBCT evaluated 30.3% of RCOs with radiographically adequate length as inadequate.[15] Therefore, considering pre-existing CBCT images and using surgical findings for validation, we assessed the *in vivo* performance characteristics of CBCT in this field.

For the detection of obturation voids, Moller et al[4] found that CBCT frequently overestimated the proportion of voids in root fillings when compared with using micro-CT for void detection. In another study that evaluated both homogeneity and length of root fillings in single-rooted teeth, image qualities of storage phosphor images and conventional film images were superior to those of limited CBCT images.[16] CBCT was found to be successful in the assessment of teeth with ideal root canal treatment and teeth with canals filled short of the apex.[17] However, patient factors such as the probability of motion artefacts or adjacent tissues were not been considered in these *ex vivo* studies. In this study, we used the microsurgical findings to confirm the absence or presence of voids as the validation to which the CBCT images were compared and calculated the sensitivity and specificity of CBCT in void detection.

As for the microsurgical findings, surgical treatment includes endodontic microsurgery and intentional replantation (IR). Endodontic microsurgery is performed to eradicate persistent infection/inflammation in teeth with previously negative outcomes from endodontic therapy.[18] IR is described as extraction of a tooth for extraoral endodontic microsurgery and replantation of the tooth in its socket.[19,20] Endodontic microsurgery and IR offer opportunities to observe RCO directly under the microscope after removing the periapical soft tissues, resecting the roots and staining with methylene blue.

The purpose of this *in vivo* study was to verify whether there is a difference in the performance characteristics of CBCT and PR in assessing the apical extension of RCOs and to evaluate the ability of CBCT in void detection using microsurgical findings as validation. Effects of patient age and tooth position on the rate of void detection of CBCT were also assessed.

Materials and methods

Sample selection

This study was approved by the Institutional Review Board of West China Hospital of Stomatology, Sichuan University, Chengdu, China. Informed consent was acquired from all participants. Data were collected from the Department of Conservative Dentistry and Endodontics at the West China Hospital of Stomatology, Sichuan University, between February 2012 and September 2015. Inclusion criteria were as follows: (i) patients requiring endodontic microsurgery or IR treatment; (ii) surgery necessitating CBCT scans for pre-surgical treatment planning, localization of root apices and evaluation of the proximity to neighbouring anatomical landmarks; and (iii) teeth scanned by CBCT pre-surgically. Exclusion criteria were as follows: (i) teeth with horizontal or vertical fractures requiring tooth extraction were found during the operation; (ii) suspected findings other than periapical pathosis were found during the operation; and (iii) photomicrography could not be completed at the root resection level or was clearly limited by the size of osteotomy. Finally, 323 tooth roots in 268 patients (57% females, 43% males), including 30 roots in 14 patients with IR, were involved in the study (Table 1). The mean age of patients was 40.1 years (standard deviation 12.6 years).

Image evaluation

Before surgery, periapical radiographs were taken with a dental X-ray machine (Gendex Expert™ DC; Gendex, Des Plaines, IL), with exposure settings of 65 kV and 7 mA. Dental intraoral E-Speed films

Table 1 Demographic distribution of cases

Characteristic	*Number of roots*
Age (years)	
≤18	23
19–30	52
31–40	66
41–50	102
51–59	58
≥60	22
Sex, male/female	139/184
Tooth position	
Maxillary, anterior	125
Maxillary, premolar	37
Maxillary, molar	51
Mandibular, anterior	21
Mandibular, premolar	33
Mandibular, molar	56

(Kodak™; Carestream Health, Rochester, NY) were used with or without a film holder. According to the manufacturer instructions, films were processed in an automatic processor (Periomat Plus; Dürr Dental, Bietigheim-Bissingen, Germany) with fresh Kodak processing solutions for 5 min at 24 °C. Evaluation of the periapical radiographs focused on the apical extension of the RCO. Radiographs were viewed under 3.6× magnifications on a standard viewing box in a dark room. The apical extension of obturation of each root canal was categorized as "overextension" when it exceeded the radiographic apex, or as "no overextension" otherwise (Figure 1).

The limited CBCT was taken with 3D Accuitomo XYZ Slice View Tomograph (J. Morita Mfg Corp, Kyoto, Japan) with a basic voxel size of 0.08 mm or 0.125 mm and field of view of 4 × 4 or 6 × 6 cm. Scans were taken according to the manufacturer-recommended protocol. CBCT images were analyzed with a built-in software (i-Dixel, one-volume viewer 1.5.0; J. Morita Mfg Corp, Kyoto, Japan) using a 23-inch monitor set to a screen resolution of 1366 × 768 pixels in a dark room. Contrast and brightness of images was adjustable with the image-processing tool of the software to achieve optimal visualization. Sagittal and coronal sections were used to assess the apical extension of RCO, which was categorized as "overextension" when the apical extension visually extended beyond the apical foramen, or as "no overextension" otherwise. Only axial CBCT sections were used to detect voids in the apical 3 mm but not voids along the root canal, to ensure that the same slice was used clinically and by CBCT. RCO was classified as "detected" when there were any visible voids in or around the root canal fillings, or as "not detected" when there were no visible voids in or around the root canal fillings (Figure 2).

All endodontic microsurgery procedures were performed by one operator in the same manner as described in a previous study.[21] With the exception of the incisions, flap elevation and suturing, all surgical procedures were performed under a surgical operating microscope (OPMI PROergo®; Carl Zeiss, Göttingen, Germany). Briefly, after local anaesthesia was administered, the flap was reflected and osteotomy was performed. Soft-tissue debris was removed, and photomicrographs were obtained under the surgical microscope. An additional 2–3 mm of the root apex was sectioned with no bevel or <10°. Resected root surfaces were stained with methylene blue. Then, another photomicrograph was taken with or without micromirrors (ObturaSpartan, Fenton, MI) under 10× to 14× magnification. The IR procedures were performed by the same operator. After local anaesthesia was administered, the surgeon extracted the tooth with a slow and weak continuous force buccolingually. The beaks of the forceps were kept on the crown of the tooth above the cementoenamel junction. The extraoral time of the tooth was kept under 15 min. During this time,

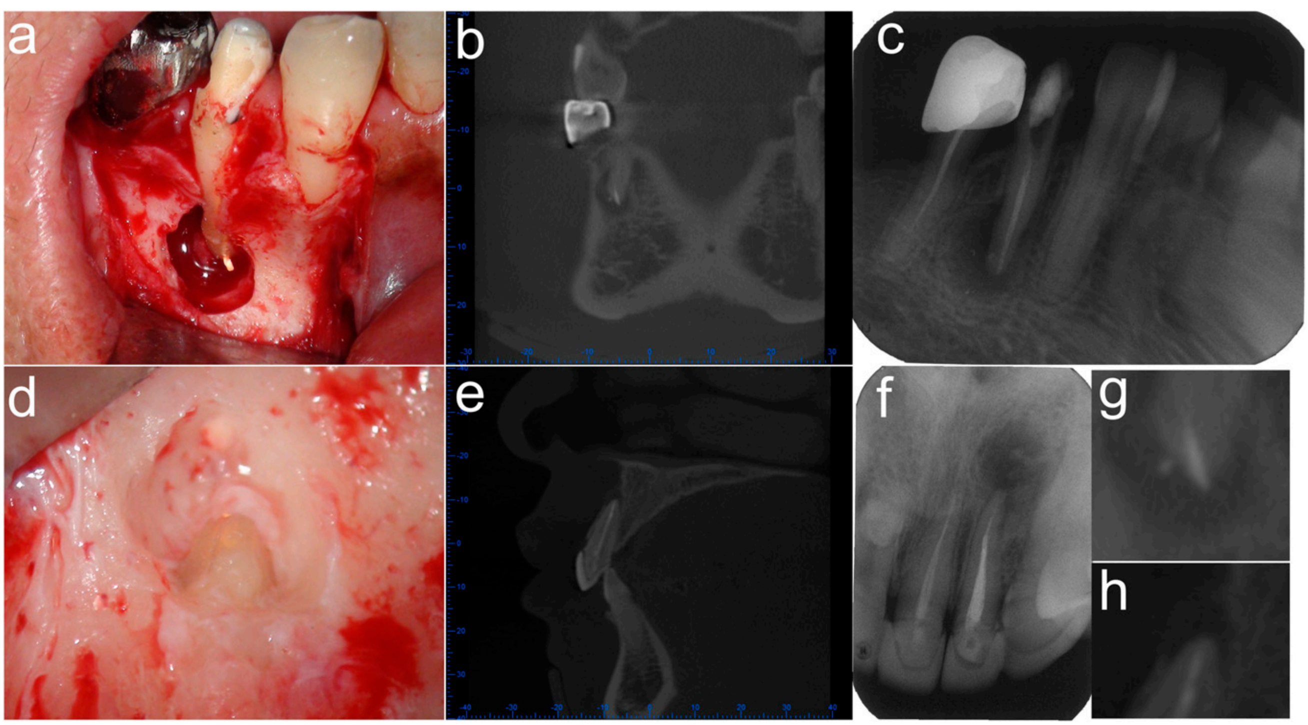

Figure 1 Apical extension of root canal obturation: Tooth 44—obturation was determined as "overextension" by photomicrography (a) and classified as "overextension" by CBCT (b), while as "no overextension" by periapical radiography (PR) (c). Tooth 21: obturation was determined as "overextension" by microphotography (d) and classified as "no overextension" by CBCT (e) and PR (f). Apical areas of the CBCT images (b, e) were magnified (g, h) respectively.

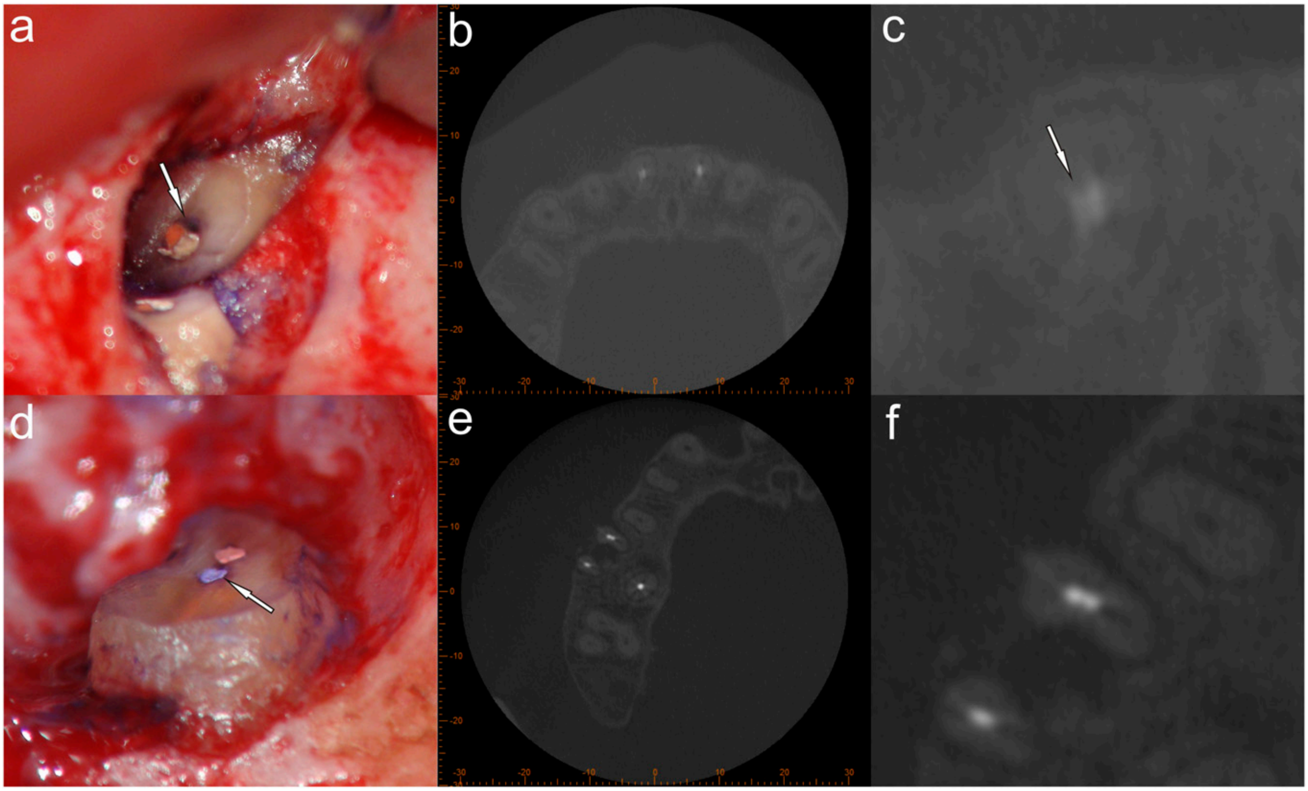

Figure 2 Detection of root canal obturation voids (white arrows): Tooth 11—voids detected by photomicrography (a) and in CBCT image in the axial plane (b). A higher magnification image of CBCT is shown (c). Tooth 16: voids detected by photomicrography (d) but not by CBCT in the axial plane (e). A higher magnification image of CBCT is shown (f).

the tooth was bathed continuously in Hank's Balanced Salt Solution (Bio Whittaker™, Walkersville, MD) to maintain the viability of the periodontal ligament.[19] Root resecting, methylene blue staining and photomicrography obtaining procedures were performed in the same manner as in endodontic microsurgery.

Photomicrographs were viewed on a desktop computer with a 23-inch monitor set to a screen resolution of 1366 × 768 pixels. They were analyzed based on colour, as voids should result in blue stains. In this study, photomicrographs were utilized as the gold standard to determinate the existence of overextension, as well as voids.

Three observers (endodontic specialists with 5 years' or more than 5 years' training each) were involved in this study. They were calibrated using 10 additional samples according to written guidelines before the investigation. The observers evaluated the images independently and then discussed their findings to reach a consensus. During the investigation, each observer randomly analyzed almost a third of the samples (each sample was coded and consisted of the corresponding PR images, CBCT images and photomicrographs). In each assessment, the observers were blind to the patient history. The time for observation and categorizing was unrestricted. Furthermore, 50 samples were randomly selected to determine intraobserver validity, and observations were made again around 2 weeks later. Interobserver validity was evaluated at this second time point.

Data and statistical analyses

Kappa analysis was applied to calculate interobserver/intraobserver agreement. Several performance parameters [sensitivity, specificity, positive-predictive value (PPV)/negative-predictive value, positive likelihood ratio (+LR), negative likelihood ratio (−LR) and 95% confidence intervals (CIs) of these parameters] of CBCT and/or PR in evaluating the apical extension and detecting voids were calculated. The χ^2 test was used to compare PR with CBCT in evaluating the apical extension, to compare CBCT with surgical findings in detecting voids and to analyze the influences of tooth position and patient age on the accuracy of CBCT in void detection. To compare interobserver/intraobserver agreement of PR with those of CBCT, one-way analysis of variance and the two-tailed Student's *t*-test were used. A value of $p < 0.05$ was considered statistically significant when one comparison was being made. Statistical analysis was performed with SPSS® v. 13.0 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). The level of significance was set at $\alpha = 0.05$.

Results

Kappa values for intraobserver and interobserver agreement were 1.0 for each observer when using photomicrography. Thus, perfect agreement was

Table 2 Intraobserver and interobserver agreement by periapical radiography (PR) and CBCT images

	PR			*CBCT*[a]			*CBCT*[b]		
Observer	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
1	0.935	0.805	0.935	1.0	0.831	0.694	0.783	0.452	0.520
2		1.0	1.0		0.898	0.847		0.627	0.480
3			1.0			0.898			0.645

[a]Evaluation of the apical extension of root canal obturations (RCOs) by CBCT images.
[b]Detection of voids of RCOs by CBCT images.
Both interobserver and intraobserver agreements of PR ($t = 7.082$, $p < 0.005$; $t = 5.449$, $p < 0.05$; respectively), as well as CBCT[a] ($t = 5.851$, $p < 0.005$; $t = 4.126$, $p < 0.05$; respectively), were higher than those of CBCT[b], while no significant differences were observed when comparing the two agreements between PR and CBCT[a] ($p > 0.05$).

generally achieved. Table 2 shows the intraobserver/interobserver agreements when evaluating PR and CBCT images. Both intraobserver and interobserver agreements of PR were superior to those of CBCT when CBCT images were used to detect voids of RCO ($t = 5.449$, $p < 0.05$; $t = 7.082$, $p < 0.005$; respectively). No significant differences were observed when comparing the two agreements between PR and CBCT when CBCT images were used to evaluate the apical extension of RCO ($p > 0.05$). For PR images, both agreements were excellent, ranging from 0.805 to 1.0. When evaluating the apical extension of RCO by CBCT, we found that either interobserver agreement or intraobserver agreement was outstanding. When evaluating the accuracy of CBCT in void detection, we found that the interobserver reproducibility was poor, and the intraobserver reproducibility was moderate; furthermore, both agreements were the lowest among the three groups shown in Table 2 ($p < 0.05$).

Figure 1 shows representative images of RCO categorized as "overextension" or "no overextension" by photomicrography (as the gold standard), CBCT and PR. Numerical results of these classifications are given in Table 3. CBCT showed superior sensitivity (0.86, 95% CI 0.76–0.93) compared with PR (0.66, 95% CI 0.54–0.76) for detecting the apical extension of obturation ($\chi^2 = 13.067$, $p < 0.005$).

According to surgical findings, there were 259 roots with voids and 64 non-void roots. When the photomicrography results were used as the validation, we found that CBCT showed poor sensitivity, poor +LR, poor −LR and moderate specificity in void detection (Table 4). In void detection, photomicrography was significantly better than CBCT ($p < 0.005$).

Most tooth roots (278 roots) were from patients aged 19–59 years, while 45 roots were from younger (age ≤ 18 years) or older patients (age ≥ 60 years). Tooth roots were mostly from the maxilla (213 roots), with the remainder from the mandible (110 roots). Neither patient age nor tooth position had any influence on the void detection rate by CBCT ($p > 0.05$, Table 5).

Discussion

Endodontic treatment failure has been associated with deficient root canal preparation and obturation, especially in the apical 3-mm area. Many previous reports have suggested that the apical extension of RCO plays key roles in determining the success of endodontic therapy[22,23] and the efficiency of bacterial elimination from the root canal system.[2] For example, removal of 3 mm of the root end reduced apical ramifications and lateral canals by 98% and 93%, respectively.[18] However, because the apical third of the root canal has a complex anatomical structure,[2] complete obturation of 3 mm of the root apex may be difficult to achieve. According to *in vitro* studies, root canal fillings rarely completely obturate the root canal.[24–26] In this study, the similar result that voids seemed to be common among the obturated roots (259/323 roots had voids) has also been shown. The presence of voids might be a cause for root canal therapy failure, although studies using a larger sample size are needed to confirm this possibility. Therefore, evaluation of RCO is an important component of clinical endodontics.

According to relevant guidelines[9] and the as low as reasonably achievable principle,[27] CBCT cannot be recommended for routine assessment of the quality of root canal filling. However, for patients with pre-existing CBCT scans, dentists could make use of these data. All CBCT and PR images in this study were pre-existing. We could not detect cases in which root canals were filled

Table 3 Performance characteristics of periapical radiography (PR) *vs* CBCT in evaluation of the apical extension of obturation

Method	*OE* (n)	*No OE* (n)	*TP* (n)	*FP* (n)	*TN* (n)	*FN* (n)	*Sensitivity*	*Specificity*	*PPV*	*NPV*
CBCT	65	258	65	0	247	11	0.86	1.0	1.0	0.96
PR	50	273	50	0	247	26	0.66	1.0	1.0	0.90
Photomicrography	76	247								

FN, number of false negatives; FP, number of false positives; No OE, number of non-overextension cases; NPV, negative-predictive value; OE, number of overextension cases; PPV, positive-predictive value; TN, number of true negatives; TP, number of true positives.
Photomicrography results were considered as the gold standard.
$\chi^2 = 13.067$, $p < 0.005$ for PR *vs* CBCT.

Table 4 Performance characteristics of CBCT in void detection using Photomicrography findings as the gold standard

	Photomicrography		*Detection of voids*	
	Detected (*n*)	Not detected (*n*)	Sensitivity	0.24 (95% CI 0.19–0.30)
CBCT			Specificity	0.67 (95% CI 0.54–0.78)
Detected (*n*)	62	21	PPV	0.75 (95% CI 0.64–0.84)
Not detected (*n*)	197	43	NPV	0.18 (95% CI 0.13–0.23)
			+LR	0.73 (95% CI 0.48–1.10)
			−LR	1.13 (95% CI 0.94–1.36)

+LR, positive likelihood ratio; −LR, negative likelihood ratio; CI, confidence interval; NPV, negative-predictive value; PPV, positive-predictive value.
Performance characteristics were calculated by considering photomicrography results as the gold standard.
$\chi^2 = 142.092$, $p < 0.005$ for CBCT *vs* photomicrography.

short of the apex by photomicrography. Therefore, we only focused on overextended RCOs when assessing the apical extension of RCOs. In the present study, both CBCT and PR underestimated the overextension of RCOs. CBCT missed 11 of the 76 overextended roots. The sensitivity in assessing the apical extension of RCOs was significantly better for CBCT (0.86, 95% CI 0.76–0.93) than that for PR (0.66, 95% CI 0.54–0.76). Intraoral PR, with the paralleling technique, is the current conventional reference standard for the evaluation of RCO.[9] The apical extension of obturation did not exceed the radiographic apex in 273 roots studied. When photomicrography was used as the reference standard, PR did not detect 26 cases of overextended roots, leading to a low sensitivity value.

The location where the canal leaves the root surface next to the periodontal ligament,[28] known as the apical foreman, does not directly correspond to the radiologic apex. In other words, an obturation that does not exceed the radiologic apex may still exceed the apical foramen position. As a result, the case may be clinically misclassified as "no overextension". Clinicians may be misled by this misclassification and unable to relieve symptoms.[29] Similarly, Li Cheng et al[15] found that CBCT classified 30.3% of RCOs with radiographically adequate lengths as "inadequate", with overextension in 13.8% of teeth and underextension in 16.5% of teeth. When the apical extension of the obturation exceeds the radiologic apex in periapical radiographs, there is no doubt that the obturation is overextended. The specificity and PPVs of CBCT and PR were 1.0, indicating that the detection of an overextended obturation by these methods can be considered valid. On the other hand, the apical extension of obturation in some roots exceeded the physiological apex by only a very small distance in photomicrographs, which might explain why CBCT missed some overextension cases. However, the specific distance at which CBCT will misjudge the overextension status requires future study.

Table 5 Influence of age of patients and tooth position on CBCT in void detection rate

	Age of patients (years)		*Tooth position (tooth roots)*	
CBCT	*≤18 & ≥ 60*	*19–59*	*Maxilla Teeth*	*Mandible Teeth*
Detected (*n*)	10	73	60	23
Not detected (*n*)	35	205	153	87

Influence of age of patients, $\chi^2 = 0.331$, $p > 0.05$; influence of tooth position, $\chi^2 = 2.002$, $p > 0.05$.

After a 3-mm apical resection, we used photomicrographs to detect whether voids existed in the apical area and evaluated the performance characteristics of CBCT in void detection. According to our results, CBCT was not suitable for detecting voids. To our knowledge, there is no *in vivo* study to determine the specific sensitivity and specificity of CBCT in void detection, compared with microsurgical findings as validation. Although CBCT provides high-quality 3D images of dental structures, the observed sensitivity of CBCT in void detection was very low (0.24, 95% CI 0.19–0.30). This finding, combined with the poor negative-predictive value (0.18, 95% CI 0.13–0.23) and +LR (0.73, 95% CI 0.48–1.10), indicated that CBCT missed many existing voids, offering one reason that CBCT should not be used to evaluate RCO. Furthermore, the specificity (0.67, 95% CI 0.54–0.78), PPV (0.75, 95% CI 0.64–0.84) and −LR (1.13, 95% CI 0.94–1.36) of CBCT suggest the high occurrence of false-positive cases. Similarly, Moller et al[4] found that CBCT axial sections obtained a higher sensitivity than six intraoral receptors, meanwhile overdiagnosing voids when micro-CT is used as validation. In consideration of void size, digital intraoral techniques were better than CBCT for detecting voids <350 μm; for voids >350 μm, all imaging techniques behaved the same.[30] Sogur et al[16] reported that the image quality of storage phosphor images and conventional film images was superior to that of limited CBCT images for the evaluation of both homogeneity and length of root fillings in single-rooted teeth. In another study that assessed root canal treatment quality, CBCT revealed inferior results compared with intraoral techniques when assessing teeth with insufficient condensation and teeth with overfilled canal treatment.[17] These previous observations and our results show that CBCT might both overestimate and underestimate the proportion of voids in RCOs. Accordingly, CBCT cannot be recommended for assessing RCO.

CBCT image quality is affected by numerous factors, such as patient factors, voxel size, signal-to-noise ratio, contrast, quality detector, reconstruction algorithms and artefacts.[31,32] In our study, artefacts might contribute to the poor performance characteristics of CBCT in void detection. When analyzing the CBCT images, observers were not always certain whether dark areas around root fillings should be defined as voids or artefacts, which might explain the lower interobserver/intraobserver reproducibility of CBCT in void detection. In a previous study which evaluated interobserver agreement of intracanal material in the diagnosis of root fracture with CBCT, it was found that the agreement in fibre post and no filling group was superior to the gutta-percha group.[33] Another study investigated the interobserver agreement in void detection and found perfect agreement in the large void size group (800 μm).[30] Therefore, the interobserver agreement in void detection might be affected by root filling material and void size. Further studies may focus on these aspects.

Beam hardening, which occurs when an X-ray beam travels through a high-density material, is a prominent artefact source that can be caused by gutta-percha, the most common material used in root canal fillings.[32,34] Many previous studies have evaluated the influence of the root canal filling material on CBCT images. One study used four CBCT devices to evaluate characteristic artefact patterns associated with gutta-percha-filled tooth root canals, reporting significant variation of artefact expression among the CBCT images.[31] In our study, voids might be sheltered by artefacts from the root canal filling material, which would lead to a poor sensitivity of CBCT in void detection; the artefacts might also mimic voids. A previous study reported that the dimensions of the root canal filling material on CBCT images were greater than the dimensions of the original root specimens.[35] Taken together, these findings might help explain the low specificity and high false-positive rate of our study. To reduce the effect of artefacts in CBCT images caused by the presence of high-density materials, the metal reduction algorithm could be used.[36,37]

Patient factors might affect the quality of CBCT images such as patient movement that might result in a minor movement during a short-time scan. Nardi et al[38] reported that motion artefacts were more frequent in younger patients (age < 10 years, 31.5%), older patients (age > 60 years, 82.2%) and mandible cases. Therefore, we analyzed the influence of patient age and tooth position on the accuracy of CBCT in void detection. However, we did not find any influence of either variable ($p > 0.05$).

The effective dose varies widely between CBCT scanners, but is frequently higher than the radiation dose for PR or panoramic radiography.[8] Radiation dose should be optimized while considering different regions. The small field of view was selected in our study to keep the radiation dose as low as reasonably achievable. Photomicrography, as a reference standard to compare both radiological techniques in the study, would have been considered the gold standard in void detection. With this gold standard, the performance characteristics of CBCT in void detection might be closer to the real situation. Because surgical treatment is an invasive procedure, we did not include any non-diseased controls. In this study, the PR images from most patients were obtained without a film holder, which plays a crucial role in the paralleling technique; consequently, the quality of the PR images might have been affected. These limitations can lead to verification and spectrum biases that might influence the result of this study. Future studies should seek to identify highly sensitive equipment that can detect subtle voids, as well as root canal-filling materials with fewer beam-hardening artefacts.

Conclusions

CBCT was superior to PR in evaluating the apical extension of RCOs. Compared with microsurgical findings as the gold standard, CBCT, with its poor sensitivity and specificity, might both overestimate and underestimate the proportion of voids in RCOs in many cases. CBCT was not suitable for evaluating the quality of RCO. Neither patient age nor tooth position had any influence on the rate of void detection of CBCT.

Acknowledgments

The authors wish to thank Mr William Bursich of The University of Chicago for providing language edit of the manuscript. This study is supported by National Natural Science Foundation of China (11272226).

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