

The ability of cone-beam computed tomography to detect simulated buccal and lingual recesses in root canals

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Abstract

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Aim To compare the ability of cone-beam computed tomography (CBCT) and digital periapical radiographs (PR) to detect simulated tissue-occupied recesses in root canals.

Methodology A standard canal was created in 30 extracted mandibular premolar roots. Each root was longitudinally split into buccal and lingual halves. In 20 teeth, a standard groove, 4 mm in length, 0.5 mm deep and 0.3 mm wide, was prepared on each root half and filled with radiolucent plasticine (a modelling clay), simulating tissue-occupied buccal and lingual recesses. In the other 10 teeth, no grooves were cut. Each root was reassembled and filled with laterally compacted

gutta-percha and sealer. PR and CBCT were used to detect the plasticine-filled grooves. The images were pooled and blindly evaluated by three calibrated examiners (A, B and C). A chi-square test was used to analyse the data.

Results Examiner A, B, C detected grooves on CBCT scans in 20, 20 and 23 teeth, respectively, of which 19, 18 and 19 were true positives. The accuracy of CBCT in diagnosing plasticine-filled grooves was 82–92% for three examiners, significantly higher than the accuracy of PR (30–33%; $P < 0.001$).

Conclusions Cone-beam computed tomography accurately detected simulated tissue-occupied buccal and lingual recesses.

Keywords: canal recesses, cone-beam computed tomography, oval canal, periapical radiography.

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Introduction

Failure to eradicate intra-canal infection could hinder healing (Happasalo *et al.* 2011). Several other problems may cause persistent apical periodontitis (AP), including vertical root fractures, missed canals, perforations, extraradicular infection, a true cyst or foreign body reaction (Nair 2004). Before venturing into a retreatment, it would be useful to know the reasons for persistent AP in order to take steps to address the

relevant problems and thus improve the prognosis (Imura *et al.* 2007).

Apical deltas and recesses in oval canals are common sites for bacterial retention and growth (Nair 2004). Furthermore, long oval canals (the long canal diameter being at least two times the short canal diameter) are present in 25% of all canals (Wu *et al.* 2000), where thorough debridement is difficult. Infected tissues and dentine chips are often left in the buccal or lingual canal recesses because of inadequate root canal debridement (Gutmann & Lovdahl 2010, Paqué & Peters 2011). In *ex vivo* experiments, hand syringe irrigation had limited ability to clean oval canals, leaving the buccal and/or lingual recesses occupied by debris (Fig. 1a; Wu & Wesselink 2001).

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These infected tissue-occupied spaces may appear as 'inadequate root fillings' or 'root fillings with voids' on digital periapical radiographs (PR) of root filled teeth (Ng *et al.* 2008), because organic tissues and bacteria are radiolucent. The prognosis seems to be affected by these factors: persistent AP was observed 26% more in teeth with inadequate root fillings as compared with teeth with adequate fillings (Ng *et al.* 2008). In a study by Liang *et al.* (2012), cone-beam computed tomography scans were used to assess the quality of root fillings and the outcome of root canal treatments, persistent AP was observed 33% more in teeth with inadequate root fillings as compared with teeth with adequate fillings. In retreating these failed root filled teeth, effective steps should be taken to clean and fill the canal addressing those previously untouched recess areas (Paqué *et al.* 2010).

However, most root canal treatments are performed with the aid of PR which provide only a sagittal (mesiodistal) view and may have limited ability to detect buccal or lingual tissue-occupied recesses. Limited-volume cone-beam computed tomography (CBCT) provides three-dimensional images and is sensitive in detecting small changes in structures (Patel 2009).

The purpose of this study was to compare the ability of CBCT and PR to detect simulated tissue-occupied recesses.

Methodology

Thirty extracted human mandibular premolars with a single straight canal, stored in distilled water immediately after extraction, were decoronated to obtain uniform roots of 12 mm in length. Each root was

embedded in self-curing resin (GC Ostron 100; GC Europe, Leuven, Belgium) and then bisected longitudinally through the canal in mesiodistal direction with a low-speed saw (Leica SP1600, Wetzlar, Germany) under water cooling, producing buccal and lingual resin root blocks. Both halves were ground successively with P350-, 400- and 600-grit sandpaper to remove the imprint of the original root canal. The 2 halves were reassembled by a G clamp (UC 2041; UNIC, Shandong, China).

Preparation of root canal

The canals in the assembled roots were prepared by using size 1 (ISO size 50) Gates Glidden drills (Dentsply Maillefer, Ballaigues, Switzerland) to a working length (WL) of 11 mm, and then the canals were flared using a step-back technique with Gates Glidden drills sizes 2–6 (ISO sizes 70, 90, 110, 130, 150) at 2 mm increments. Finally, a size 50, .02 taper K-file (Dentsply Maillefer) was used to smooth the canal wall, resulting in a final standardized canal size 50, .10 taper. Each canal was irrigated with 2 mL of 2.5% sodium hypochlorite (NaOCl) solution between instruments, using a syringe and 27-gauge needle.

Preparation of grooves

The root blocks were disassembled into two halves again. The roots were randomly divided into two groups. In one group ($n = 20$), a customized ultrasonic tip (ET 40; Satelec, Merignac, France) was used to prepare a standard groove of 4 mm in length, 0.5 mm deep, 0.3 mm wide in the wall of each root half

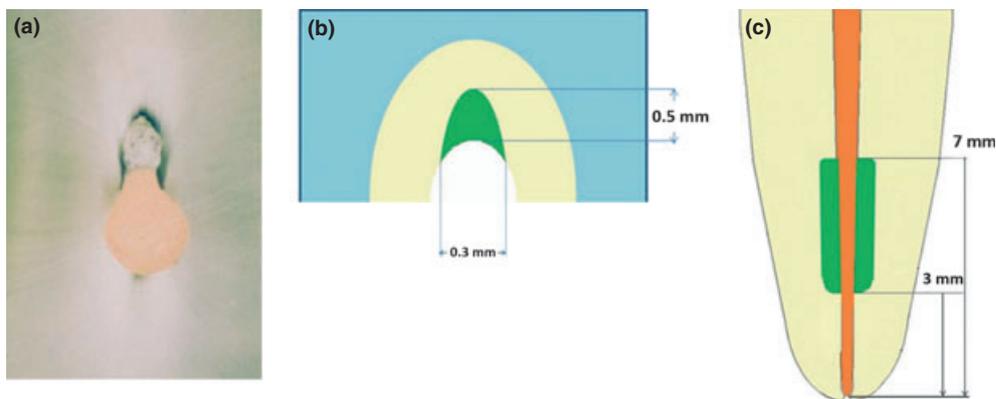


Figure 1 (a) A cross-section of a filled oval canal in mandibular incisor. Two-thirds of the uninstrumented recess excluded from the round preparation was occupied by debris (grey). (b,c) Schematic representations of the standardized root canal model, cross-section (b) and the standardized groove (c). Yellow: root dentin, orange: gutta-percha, green: plasticine-filled groove.

3–7 mm short of apex, as shown in Fig. 1(b,c). A periodontal probe (Hu-Friedy, Chicago, IL, USA) with an adapted 0.3-mm-wide tip was used to measure and verify the dimensions of each groove. Before filling, each groove was filled with radiolucent plasticine, a modelling clay (DongYang Taikang Stationery Co.Ltd. DongYang, China), to simulate tissue-occupied buccal and lingual recesses. In another group ($n = 10$), no grooves were cut in the canal wall. All grooves were completely filled with plasticine but none was placed outside the groove.

Filling of root canals

The two halves of each specimen were reassembled tightly by a G clamp and sealed on the outer surface with a bonding agent (Cyanoacrylate; Jingtong, Shanghai, China). Each canal was filled with laterally compacted gutta-percha cones (Dentsply Maillefer) and AH Plus sealer (Dentsply De Trey, Konstanz, Germany). Sealer was introduced into the canal twice using a lentulo spiral (Dentsply Maillefer) rotating at 400 rpm to 2 mm short of WL. A size 50 master gutta-percha cone (Dentsply Maillefer) was then lightly coated with sealer and was placed into the canal to the full WL. Lateral compaction was achieved in each canal by using accessory gutta-percha cones (size 25) and a size-B endodontic finger spreader (Dentsply Maillefer) that initially approached to 1 mm short of the full WL. At the end, the coronal orifice was sealed with zinc oxide-based temporary filling material Ceivitron (DongQuan, Tai-wan, China).

Radiographic assessments

Both PR and CBCT were used to detect plasticine-filled grooves. During exposures, a 20-mm-thick water phantom was placed around the resin root blocks to simulate soft tissue (Zhang *et al.* 2011). Radiographs were taken with the Digora Optime (Soredex, Helsinki, Finland) digital imaging system using a specially designed holder (Fig. 2) to provide a standardized projection geometry in the buccolingual direction. Exposures (0.06 s) were obtained with a MinRay dental X-ray unit (Soredex) operating at 60 kV and 7 mA. The digital radiographs were obtained by immediately scanning the phosphor plates (SPPs) after exposure (Dfw v.2.5.; Soredex). The selected scanning resolution was 400 dpi. The raw data images were then processed and saved as 8-bit images. The CBCT

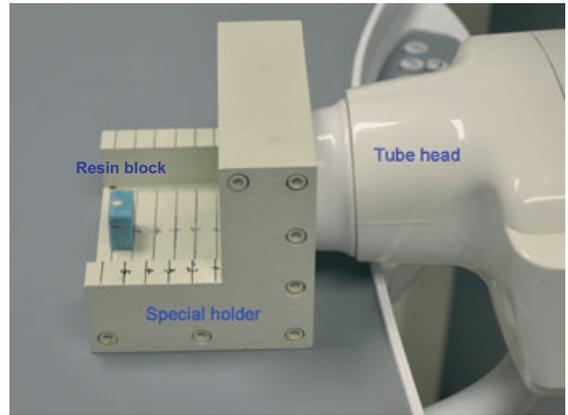


Figure 2 The specially designed holder used in radiographic assessments, which provided a standardized projection geometry in the buccolingual direction.

images of teeth were made with a 3DX-Accuitomo CBCT scanner (J. Morita MFG. CORP, Kyoto, Japan), with the 4×4 cm field of view (FoV) selection operating at 60 kVp, 4–5 mA and an exposure time of 17.5 s. The voxel size was 0.125 mm. The CBCT images were reconstructed using the system's proprietary software (i-Dixel 3DX; J. Morita MFG. CORP). The images were only studied in typical axial, coronal and sagittal planes.

All images were pooled and evaluated twice by three calibrated dentists: an endodontist, a radiologist and a postgraduate student, independently and blindly. The examiners were informed that plasticine-filled grooves of 3–4 mm in length were present in the middle third of canal in some specimens. The viewing took place in a room with dimmed lights. PR and CBCT images were displayed on a 22-inch Dell E228WFP flat panel monitor (Dell, Round Rock, TX, USA) with a resolution of 1680×1050 pixels. There was a minimum 1 week interval between the first and second evaluations.

Histological assessment

All root-resin blocks were stored in water before sectioning. Each root was horizontally sectioned 4 and 6 mm from the apex using an Isomet low-speed saw (Leica SP1600 Saw Microtome; Leica Biosystems Nussloch GmbH, Heidelberg, Germany). All cross-sections were viewed through a stereomicroscope (ZOOM-630E; Chang-fang Optical Instrument Co., Shanghai, China) at a magnification of $40\times$.

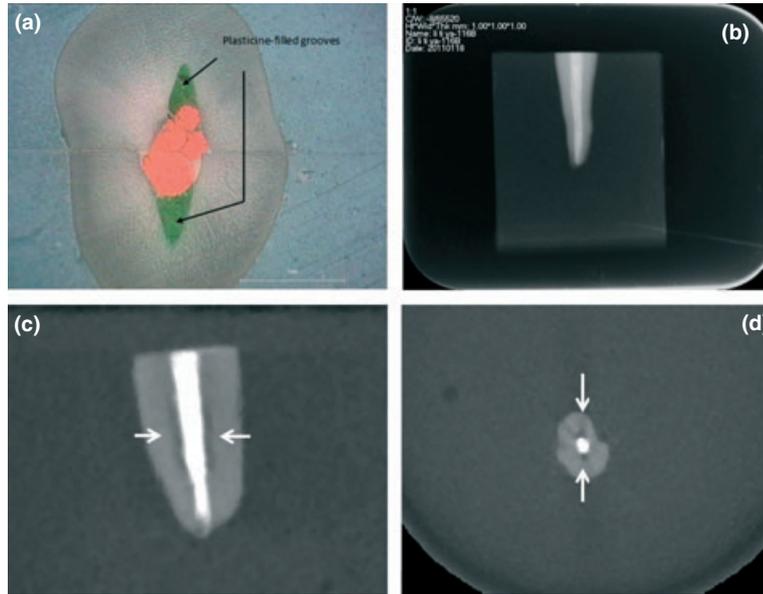


Figure 3 (a) The histological cross-section of root filled with laterally compacted gutta-percha. The plasticine-filled grooves (green) were confirmed (arrows; Original magnification $\times 40$). (b) Grooves were not visible on PA. On the coronal (c) and axial (d) CBCT slices, grooves were visible (arrows).

Statistical analyses

The inter-examiner agreement for CBCT diagnosis was assessed by using Fleiss' Kappa. The intra-examiner agreement was assessed by using Cohen' Kappa. A chi-square test was used to analyse the data from PR and CBCT for the detection of plasticine-filled grooves. The level of significance was set at $\alpha = 0.05$.

Results

All buccal and lingual plasticine-filled grooves were confirmed by histological examination (Fig. 3).

The sensitivity, specificity, true and false positives and negatives and accuracy of CBCT scans and PR in the detection of plasticine-filled grooves are presented in Table 1. The accuracy of CBCT in diagnosing

plasticine-filled grooves was 82–92% for three observers, significantly higher than the accuracy of PR (30–33%; $P < 0.001$).

The kappa value for the overall inter-examiner agreement was 0.60. The kappa value for intra-examiner agreement was 0.56, 0.92, 0.65 for examiner A (radiologist), B (endodontist) and C (postgraduate student), respectively.

In all roots where plasticine-filled grooves were detected by CBCT, grooves were observed on both coronal views (buccolingual views) and axial views, but not on sagittal views (mesiodistal views; Fig. 3).

Discussion

In the present study, 30 mandibular premolar roots, 20 (67%) with plasticine-filled grooves and 10 (33%)

Table 1 The sensitivity, specificity, true positives (TP), false positives (FP), true negatives (TN), false negatives (FN) and accuracy in the detection of simulated tissue-occupied buccal and lingual recesses, evaluated by a radiologist (A), endodontist (B) or a postgraduate student (C)

Observers	Radiographic technique	Sensitivity	Specificity	TP	FP	TN	FN	Accuracy	P value
A	PR	0	0.9	0	1	9	20	0.3	<0.001
	CBCT	0.925	0.9	19	1	9	1	0.917	
B	PR	0	1	0	0	10	20	0.33	<0.001
	CBCT	0.975	0.8	18	2	8	2	0.917	
C	PR	0	1	0	0	10	20	0.33	<0.001
	CBCT	0.95	0.55	19	4	6	1	0.817	

PR, periapical radiographs; CBCT, cone-beam computed tomography.

without plasticine-filled grooves, were examined with PR and CBCT. The percentages of roots with and without grooves in this study were similar to the percentages of root fillings with and without radiographically visible voids as evidenced by bidirectional radiographs (Wu *et al.* 2009). As the diameter of a root canal is usually wider buccolingually than mesiodistally (Wu *et al.* 2000), grooves were cut in the buccal and lingual halves of roots to mimic recesses in long oval canals (Lee *et al.* 2004, Rödiger *et al.* 2010). The prepared grooves were filled with radiolucent plasticine, simulating tissue-occupied recesses, and a standard canal of size 50, .10 taper was created to minimize the effect of diverse root canal morphology.

Huybrechts *et al.* (2009) concluded that all artificial voids larger than 0.3 mm diameter inside root fillings were detected by PR. Therefore, PR should have sufficient resolution to detect plasticine-filled grooves (4 mm long, 0.5 mm deep and 0.3 mm wide). The plasticine-filled grooves were visible on the coronal and axial CBCT views, rather than the sagittal views. However, as only sagittal views are available on PR, these grooves were not demonstrated by PR (Fig. 3).

All examiners made 'false positive' observations with CBCT images (Table 1). In total, 5–17% of the CBCT-diagnosed plasticine-filled grooves were false positives (Table 1). This could be explained by beam hardening artifacts that CBCT can produce, which appear as streaks and dark bands between two dense objects. These artifacts are caused by the inherent polychromatic nature of the projection X-ray beam. Lower energy photons are absorbed in preference to high-energy photons when passing a dense object. The streaks and dark bands present at the interface root filling–root canal wall could be mistakenly scored as voids on CBCT images (Lane *et al.* 1976, Scarfe & Farman 2008, Huybrechts *et al.* 2009, Patel 2009). Soğur *et al.* (2007) compared the subjective quality of CBCT, storage phosphor plate (SPP) and F-speed analogue film images for diagnosing quality of root fillings and reported that the presence of streaking artifacts from gutta-percha and sealer may compromise the quality of images. The radiolucent line between the root filling and canal wall extending all the way apically is called a 'mach band' (Huybrechts *et al.* 2009), and one should be cautious not to score this as a void.

Another possible reason for the false positives was the calibration of examiners who were informed that the plasticine-filled grooves were present in the middle part of the root canal. Although CBCT has made it

possible to visualize the quality of root fillings in three-dimensions, clinicians can make different diagnoses. The kappa value for the overall inter-examiner agreement was 0.60. The intra-examiner disagreement each observer ($\kappa = 0.56–0.92$) indicated that all clinicians and radiologists need training on interpreting CBCT images of root fillings.

One limitation of this study was that the soft tissue simulation used was a 20-mm water phantom. This may have introduced a different scattering radiation which could have influenced the image contrast resolution when compared with the real soft tissue, although previous studies had confirmed that water could serve as a simulator of soft tissue (Shi & Li 2009, Zhang *et al.* 2011).

Overall, CBCT detected 90% of the buccal and lingual plasticine-filled grooves (Table 1; Fig. 3), whereas none were detected by PR. As CBCT is superior to PR in the detection of missed canals (Huomonen *et al.* 2006), vertical root fractures (Hassan *et al.* 2009, Zou *et al.* 2011) and stripping perforations (Shemesh *et al.* 2011), it would be useful to perform CBCT scans to check the reasons for endodontic failures in cases where the cause is not clear. However, the 'as low as reasonably achievable' (ALARA) principle should be followed and thus a small volume CBCT should be utilized.

Conclusion

Cone-beam computed tomography accurately detected simulated tissue-occupied buccal and lingual recesses. However, 5–17% of the CBCT-diagnosed plasticine-filled grooves were false positives.

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