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Detection and measurement of artificial periapical lesions by cone-beam computed tomography

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Abstract

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Aim To test the ability of periapical radiography (PA) and cone-beam computed tomography (CBCT) to determine the presence/absence of periapical lesions and examine the reliability of volumetric measurements of periapical lesions on CBCT scans.

Methodology After tooth extractions in human mandibles, bone defects were cut at the base of extraction sockets to mimic periapical bone lesions. The teeth were then returned into the extraction sockets. Sixty-three roots of anterior teeth, premolars and molars with artificial periapical lesions and 37 roots without lesions were examined with PA and CBCT. Presence/absence of periapical lesion was noted. The CBCT-based volume of each lesion (Vct) was measured using Amira software 5.4 (Visage Imaging GmbH, Berlin, Germany). A replica of each lesion was created using silicone impression material, and the volume of the replica was measured using a water displacement method, representing the physical volume of the lesion (Vp). Regression analysis was used to test the correlation between the Vp and Vct values.

Results The positive and negative predictive values and accuracy for CBCT in diagnosing periapical lesions were all 1, compared with 1, 0.64 and 0.79 for PA diagnosis. Twenty-one (33%) lesions were undetected by PA. The Vp (21.5 ± 11.0 mm^3) and Vct (21.4 ± 11.5 mm^3) values of 63 lesions were highly correlated ($R^2 = 96.9\%$, $P < 0.001$).

Conclusion Cone-beam computed tomography is more accurate than PA in diagnosing periapical lesions associated with mandibular teeth. The volumes of artificial mandibular periapical lesions were accurately measured with CBCT data.

Keywords: artificial periapical lesion, cone-beam computed tomography, periapical radiography, volumetric measurements.

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Introduction

Clinical outcome studies constitute an important part of endodontic research and provide essential information to the patient and dentist regarding treatment options and the prognosis (Friedman *et al.* 2003).

Periapical radiography (PA) is commonly utilized as the principal objective tool for assessing the outcome of treatment (Ng *et al.* 2007). With strict radiographic criteria, only complete resolution of periapical radiolucency at recall suggests that root canal treatment has been successful. With loose radiographic criteria, both complete resolution and reduction in size of existing radiolucency at recall suggest treatment success (Friedman *et al.* 2003, Ng *et al.* 2007, 2008). *Ex vivo* and *in vivo* studies have confirmed that PA is of limited use for detecting periapical radiolucencies

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(Bender & Seltzer 1961, van der Stelt 1985, Bender 1997, Jorge *et al.* 2008, Paula-Silva *et al.* 2009a). Periapical lesions confined to the cancellous bone are not always seen on radiographs, owing to the overlying cortical plate masking the periapical lesion (Gröndahl & Huumonen 2004). Healing of periapical lesions that are not detected on PA pre-treatment (Patel *et al.* 2012a) could obviously not be evaluated. According to the European Society of Endodontology (2006), initial root canal treatments should be followed for up to 4 years. In cases with persistent or enlarged periapical radiolucencies, a retreatment is considered. Therefore, proper identification of periapical lesions and their size is important for treatment planning purposes.

Cone-beam computed tomography (CBCT) has gained considerable popularity since its introduction in the 1990s. It has the potential to provide more accurate information about the presence/absence of periapical lesions at recall (Lofthag-Hansen *et al.* 2007, Christiansen *et al.* 2009, Patel 2009, Paula-Silva *et al.* 2009a, Sogur *et al.* 2009, Durack *et al.* 2011, Liang *et al.* 2012). However, the accuracy of CBCT in diagnosing apical periodontitis (AP) and measuring the size of periapical lesions has not been adequately investigated (Petersson *et al.* 2012).

The aim of this study was to test the ability of PA and CBCT to determine the presence/absence of periapical lesions and examine the reliability of volumetric measurements of periapical lesions with CBCT scans.

Materials and methods

A total of 15 dry human mandibles were provided by the Department of Anatomy, Faculty of Medicine, Peking University, Beijing, China. Age and gender were not available.

As shown in Fig. 1(a), a template was created using self-curing resin (GC Ostron 100; GC Europe, Leuven, Belgium) to ensure complete reseating in exactly the same position into its own mandible during radiographic examinations (Durack *et al.* 2011).

Each mandible was soaked for 90 min in warm water with hand washing liquid to reduce the surface tension of the bone and increase its water absorption (Patel *et al.* 2009). The teeth were subsequently a traumatically removed from their sockets. Using a prosthetic plaster saw (No. 13-210 YDM Corporation, Tokyo, Japan), each mandible was sectioned into three bone blocks: two posterior and one anterior (Fig. 1a). The three blocks were further split into six labial (buccal) and lingual bone parts (Fig. 1b) by coronally (sagitally) sectioning each bone block through the extraction sockets using the same saw.

One hundred roots without root fillings, associated periapical lesions, root resorption or root fracture were included. In the cancellous bone at the base of the extraction sockets of 63 roots, bone defects of different shapes and sizes were cut with dental burs (316-FGSL Komet USA, Rock Hills, SC, USA) to mimic periapical bone lesions (Fig. 1b). The total 31

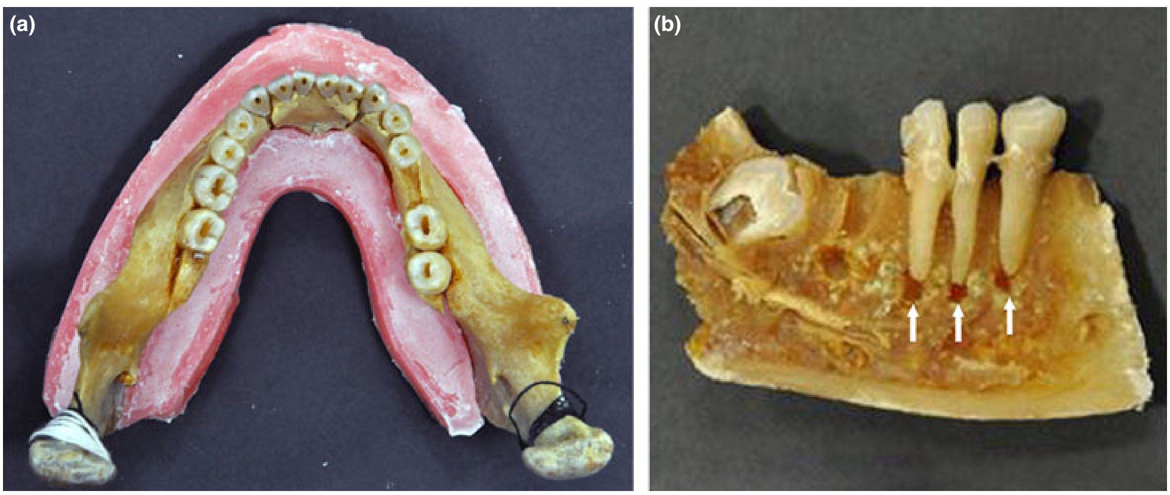

Figure 1 (a) Two posterior and one anterior tooth blocks were reseated into a template created using self-curing resin (pink colour). (b) a posterior teeth block had been sagittally split into two parts. Bone defects were cut at the base of extraction sockets in one part to mimic periapical lesions (white arrows).

spherical lesions of approximately 2–4 mm diameter, 16 wide lesions (5 mm mesiodistal diameter and 2 mm buccolingual diameter) and 16 deep lesions (5 mm buccolingual diameter and 2 mm mesiodistal diameter) were prepared in anterior teeth, premolars and molars, 21 lesions for each tooth position (Fig. 2). The lamina dura between extraction socket and periapical bone defect was removed. The linear dimensions and shapes of these artificial lesions were designed according to data from clinical observations (Sundqvist *et al.* 1998, Lofthag-Hansen *et al.* 2007). Lesions with different sizes and shapes were equally distributed in different tooth positions. In the other 37 roots, periapical bone defects were not cut.

After creation of the artificial periapical bone lesions, the teeth were repositioned into the extraction sockets, and the mandibles were reseated into the templates (Fig. 1a).

Radiographic examination

Prosthetic dental wax 12 mm thick was used between the X-ray tube and the mandible as a soft tissue substitute for both PA examinations and CBCT scans (Caldas *et al.* 2010).

Periapical radiographies were obtained using standardized condition: a dental X-ray machine (Planmeca Intra, Helsinki, Finland) was operated at 70 KV, 10 mA and 20 cm distance from the digital imaging plate (Digora Optime, Soredex, Helsinki, Finland).

Cone-beam computed tomography scans were acquired with a 3D Accuitomo-XYZ Slice View Tomograph Scanner (J. Morita MFG. CORP, Kyoto, Japan), with a 4 × 4 cm field of view (FoV) selection and operating conditions of 70 kVp, 3–5 mA and an exposure time of 17.5 s. The voxel size was 0.125 mm. The CBCT data were reconstructed using the system's proprietary software (i-Dixel; J.Morita MFG. CORP) with 0.25-mm-thick slices at an interval of 0.125 mm.

Diagnosis of periapical lesions

A periapical lesion was diagnosed when a radiolucency associated with the radiographic apex was at least twice the width of the periodontal ligament space (Low *et al.* 2008, Patel *et al.* 2009, Bornstein *et al.* 2011). Two observers, an endodontist and a radiologist, were asked to separately view all images of 100 teeth in 15 mandibles in a random order and individually determine the presence or absence of a

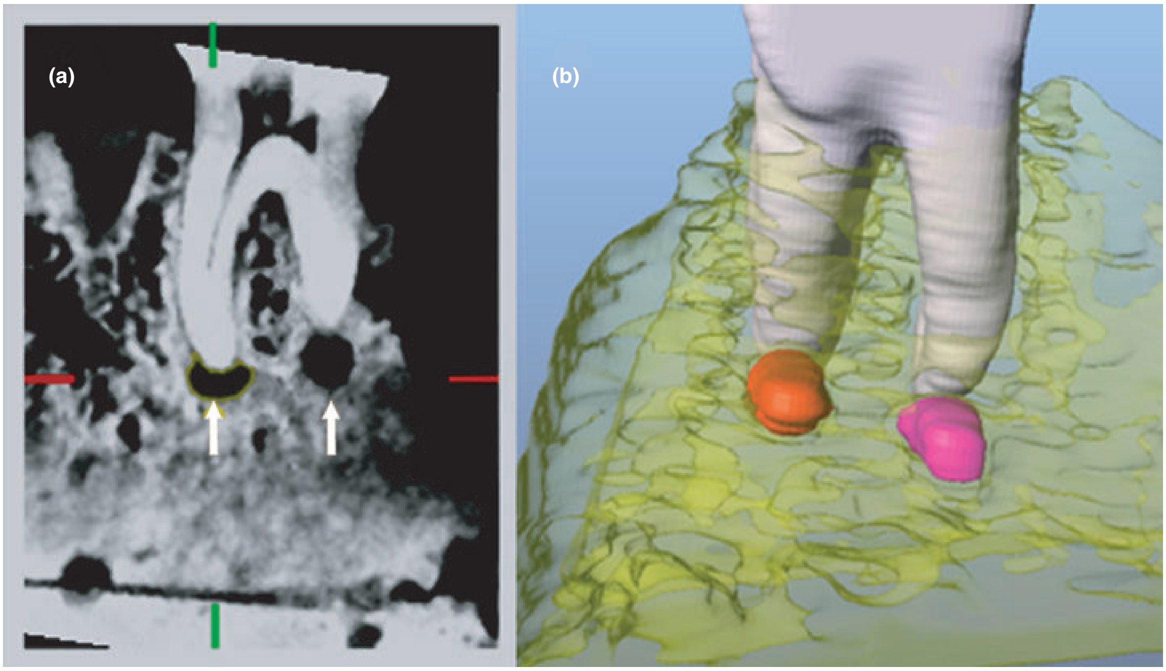

Figure 2 (a) Sagittal image on CBCT scans of a mandibular molar, showing periapical lesions in the distal and mesial roots (arrows). (b) a 3-D reconstruction of periapical bone defects in (a) created with Amira software.

periapical lesion for each tooth. In case of disagreement in diagnosis, a consensus was reached after discussion.

The assessment of the PA revealed an inter- and intra-examiner agreement >0.75 (Cohen's kappa). Inter- and intra-examiner agreement of CBCT assessment was >0.90 (Cohen's kappa) (Peacock & Peacock 2010).

Measurements of lesion volume on CBCT scans

Volumetric data of teeth with periapical lesions were exported in DICOM3 format (Digital Imaging and Communication in Medicine). The data were imported into Amira 5.4.3 (Visage Imaging GmbH, Berlin, Germany) and displayed in a random order to a radiologist who was trained and experienced in CBCT segmentation with local threshold-determining algorithm (Chang *et al.* 2013). The observer was advised to segment a periapical lesion on the involved tooth. Extraction of interest area was completed automatically. The observer performed manual adjustment for each lesion and measured the volume of lesions twice with a 2-week interval, and the intraclass correlation coefficient (ICC) was 0.991. The values of the first measurements were used as the CBCT-based volume (Vct).

Physical volume measurements

A replica was created using Rapid Soft silicone impression material (Coltene/Whaledent, Altstätten, Switzerland). The internal surface of each bone defect was first coated with a thin layer of melted prosthetic dental wax facilitating separation of the replica from the bone defect. A 10-mL graduated cylinder with gradations of 0.1 mL (Sinopharm Chemical Reagent Co., Ltd, Beijing, China) was used to measure the physical volume of the silicone replica using a water displacement method, as described previously (Agbaje *et al.* 2007, Liu *et al.* 2010). The volume of the replica represented the physical volume (Vp) of the lesion.

Statistical analysis

A chi-square test was used to compare the accuracy of PA and CBCT in diagnosis of periapical lesions. Binary logistic regression analysis was performed with the PA data to analyse the influence of tooth position, lesion volume and shape on the detection of lesions. Regression analysis was used to test the correlation between Vct and Vp values with a null hypothesis (correlation coefficient equal to zero). $R^2 > 64\%$ and $P < 0.05$ were considered to indicate a strong relationship (Kamburoğlu *et al.* 2010). ANOVA was used to compare Vp values for different tooth groups.

The statistical analyses were performed using SPSS (version 16.0, IBM, Chicago, USA). The level of significance was set at $\alpha = 0.05$.

Results

The physical volumes of 63 artificial lesions were 6.7–46.3 mm^3. The sensitivity, specificity, positive (PPV) and negative (NPV) predictive values and accuracy of PA and CBCT are shown in Table 1. CBCT was found to be more accurate than PA in diagnosing periapical lesions in mandibles ($P < 0.001$).

Twenty-one lesions with volumes of 6.7–41.3 mm^3 were not seen on PA. Detection of lesions with PA was significantly influenced by tooth position ($P = 0.014$) and lesion volume ($P = 0.024$) rather than by lesion shape ($P = 0.754$) (spherical, wide and deep-shaped lesions). Fifty percentage of lesions associated with premolars and molars were invisible; only 5% of the lesions with anterior teeth were invisible.

The physical volumes of lesions on anterior teeth (18.7 ± 11.0 mm^3), premolars (21.6 ± 9.4 mm^3) and molars (23.9 ± 12.3 mm^3) were comparable ($P = 0.305$). The Vp (21.5 ± 11.0 mm^3) and Vct (21.4 ± 11.5 mm^3) values of 63 lesions were highly correlated ($R^2 = 96.9\%$, $P < 0.001$) (Fig. 3). CBCT underestimated the volume of lesion in 32 cases and overestimated the volume in 30 cases. The maximum percentage of deviation in volume was 18.0% in overestimations and −15.0% in underestimations, and the 95% confidence interval was between −2.8% and 1.4%. In one case, the Vct was equal to Vp.

Table 1 Accuracy of PA and CBCT in diagnosing artificial periapical bone lesions

	TP	FP	TN	FN	Sensitivity	Specificity	PPV	NPV	Accuracy
PA	42	0	37	21	0.67	1	1	0.64	0.79
CBCT	63	0	37	0	1	1	1	1	1

TP, true positives; FP, false positives; TN, true negatives; FN, false negatives; PPV, positive predictive value; NPV, negative predictive value.

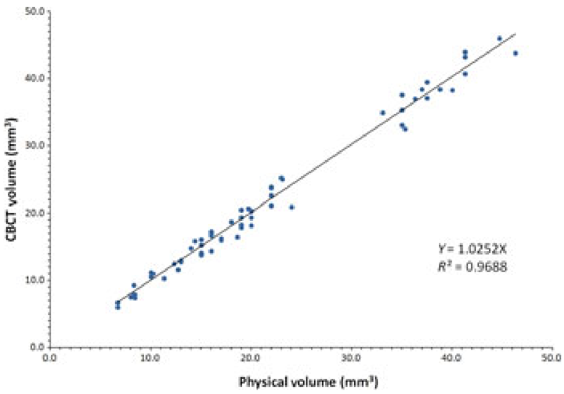

Figure 3 Correlation between physical volumes (Vp) of artificial periapical lesions and CBCT-based volumetric measurements (Vct). The high linear regression coefficient R^2 = 96.9% between Vp and Vct demonstrates the high reliability of the CBCT-based volumetric measurements.

Discussion

Periapical lesions are often present within the cancellous bone without cortical bone involvement (Katebzadeh *et al.* 1999). In previous *ex vivo* studies, periapical bone defects have been produced by drilling holes in the cancellous bone with or without applying acid over varying intervals of time (Petersson *et al.* 2012). In the present study, periapical bone defects were drilled without using acid, which allows accurate measurements of the size of the defects.

One observer performed volumetric measurements with CBCT data twice, and the measurements were reproducible (ICC = 0.991). The CBCT volumes of lesions were compared with their physical volumes of lesions (gold standard); the high linear regression coefficient R^2 = 96.9% (Fig. 3) confirms the high reliability of the measurements. Low-degree over- or underestimations were observed with a 95% confidence interval −2.8–1.4%. Recently, Mischkowski *et al.* (2007) found volumetric measurements in human maxilla and Ahlowalia *et al.* (2013) found volumetric measurements in bovine bone to be accurate and reliable.

Discontinuity of the lamina dura at the apex was often observed in AP cases (Paula-Silva *et al.* 2009b), but does not prove the presence of AP because the lamina dura is sometimes unvisible on PA of healthy teeth. In the current study, the lamina dura was removed at the apex of all teeth with artificial lesions. It has been speculated that when the lamina dura is affected, the area of rarefaction becomes more apparent (Gröndahl & Huumonen 2004). Furthermore, the identification of bone defects in this study could be easier as compared to the clinical situation because lesions were cut with a bur and thus had a sharp border. Furthermore, the bone cavities were left empty, whilst endodontic lesions are filled with tissue. Even under these experimental conditions, a high percentage (33%) of undetected lesions was noted. PA detected only 50% of bone lesions with a diameter of 2–5 mm in the premolar and molar regions where the cortical bone is thick (Huumonen & Ørstavik 2002). PA was previously shown to have a low NPV in diagnoses of periapical lesions, specifically 0.35 by Stavropoulos & Wenzel (2007) and 0.38 by Patel *et al.* (2009). For CBCT, the NPV was one in the present study and in the study by Patel *et al.* (2009) (Table 1).

In outcome studies, reduction in lesion size at recall has been used as criteria for success (Ng *et al.* 2007). Importantly, the change in size of periapical radiolucency after treatment is not always assessable with PA because many periapical lesions are invisible on PA pre-treatment (Patel *et al.* 2012a) and at recall (Patel *et al.* 2012b). Therefore, PA may not only underestimate the number of teeth with AP both pre-treatment and at recall, but also underestimate the number of teeth where the lesion has decreased or increased after treatment.

Although CBCT is superior to PA in diagnosing periapical lesions, the disadvantages of CBCT in clinical practice, such as higher cost and a potentially higher radiation dose, should be considered (AAE & AAMOR 2011). When a CBCT scan is considered or prescribed, the ALARA principles must be adhered to (Farman 2005, Patel & Horner 2009).

Conclusions

With the limitations of this study, CBCT was more accurate than PA in the identification of periapical lesions associated with mandibular teeth. Volumes of periapical bone lesions in mandibles were accurately measured using CBCT scans and Amira software.

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