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RESEARCH

Detectability of chemically induced periapical lesions by limited cone beam computed tomography, intra-oral digital and conventional film radiography

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Objective: Our aim was to compare the Accu-I-Tomo (3DX), the Digora® Optime image plate system and F-speed film in detecting chemically created apical lesions.
Methods: Lesions were created by applying perchloric acid apical to extracted teeth in jaw specimens for 1, 1.5 or 2 h. After being repositioned, teeth were radiographed with Accu-I-Tomo limited cone beam CT (LCBCT), Digora® Optime storage phosphor plates (SPP) and F-speed films. Six observers scored the presence of lesions using a five-grade scale. The accuracy of each observer and modality was assessed through receiver operating characteristic (ROC) analysis and A_z values were compared using two-way ANOVA. Pairwise comparisons of imaging systems were carried out using the Mann–Whitney *U*-test. Differences in A_z values were compared using Friedman and Dunn's tests. Kappa (κ) was used to measure interobserver agreement.
Results: The A_z values were larger for LCBCT than for SPP and film for all acid durations. For 1 h of acid duration a significant difference was found between LCBCT and film ($P=0.02$) and between LCBCT and SPP ($P=0.0043$), For 1.5 h a significant difference ($P=0.006$) was found between LCBCT and SPP only. For 2 h acid duration, there was no significant difference between LCBCT and film or SPP ($P>0.05$). Between SPP and film no significant difference was found for any acid duration ($P>0.05$). κ ranged between fair and moderate for LCBCT and between slight and fair for SPP and film.
Conclusion: LCBCT images provided better than or similar detectability as film and SPP images of chemically created periapical lesions.
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Keywords: computed tomography; cone beam; periapical lesion; radiology

Introduction

Radiography plays a major role in the detection of osseous abnormalities in the jaw bones. A periapical bone lesion visualized by radiography is the only sign of asymptomatic apical periodontitis.[1] However, periapical pathosis can exist without apparent radiographic change. It is still controversial what volume and character of bone must be lost before radiographic detection is possible.[2] Several studies have shown that bony lesions can be detected only if they involve the cortical bone layer, and that loss of trabecular pattern is discernible only when the junction between cortical and cancellous bone is eroded.[3–5] This is contradictory to the results of studies stating that periapical lesions confined to cancellous bone can be detected radiographically.[1,6] In addition to lesion extent, radiographic detection depends on several other factors, such as the thickness and degree of mineralization of the surrounding bone, the irradiation geometry and the resolution of the imaging system.[7–9]

Digital imaging techniques have created challenging opportunities for dental radiographic diagnosis. Digora was the first digital system for dental radiography based on a photostimulable phosphor technology.

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Studies have compared Digora® (Soredex, Helsinki, Finland) images with conventional radiographs in many fields of dentistry, such as endodontic length determination, caries diagnosis and assessment of periapical lesions.[10–14] These studies have found the diagnostic accuracy of conventional film and storage phosphor plate (SPP) systems to be quite similar. However, intra-oral radiography, whether film based or digital, has many inherent limitations. A fundamental one is that the three-dimensional (3D) anatomy is collapsed into a two-dimensional (2D) surface, which causes image features representing different anatomical structures to be superimposed. Features of diagnostic interest may therefore be obscured and diagnostic accuracy decreased. In 2000, limited cone beam CT (LCBCT) was introduced allowing 3D imaging of the hard tissues in small volumes of the jaws.[15] Its use has been reported for dental implant planning,[16] assessment of impacted teeth[17] and examination of temporomandibular joints.[18,19] A few studies have been published comparing LCBCT with intraoral radiography for the detection of periapical lesions.[20,21]

The aim of this study was to compare the diagnostic accuracy of Accu-I-Tomo (3DX) (Morita, Tokyo, Japan), the Digora® Optime (Soredex) image plate system and F-speed film (Eastman Kodak, Rochester, NY) for the detection of chemically created periapical lesions in dry skulls.

Materials and methods

Specimens

12 dry human mandibles were selected on the basis that they contained first and/or second premolars with no restorations, no previous root canal therapy and no evident periapical pathosis. The teeth meeting the criteria were extracted from jaw specimens using surgical elevators and forceps, applying a minimal amount of force. After the sockets were visually inspected to exclude root or bone fractures, the teeth were repositioned and radiographed to confirm proper repositioning and to ensure that no apical pathosis could be seen.

Lesion creation

All teeth included in the study were imaged with three different imaging modalities prior to any acid application (lesion creation) and the resulting images (teeth with intact periapical areas) were used as controls. The group of images was named the 0 h acid duration group.

Lesions were created in the periapical areas of all of the previously radiographed teeth as follows. After removal of the teeth a cotton pellet saturated with 0.05 ml of 70% perchloric acid was placed at the bottom of each socket. It has been reported that this method produces lesions with diffusely defined borders that more closely resemble naturally occurring periapical lesions than do drilled lesions.[22–24] Prior to the radiographic examinations, the cotton pellets were removed and the sockets washed with water and dried with cotton-tip applicators. The teeth were then repositioned in their sockets and new radiographs were taken. After each exposure, the tooth was removed and a new cotton pellet saturated with fresh acid solution was placed at the bottom of the socket. This sequence was repeated at time intervals of 0 h, 1 h, 1.5 h and 2 h.

Radiographic technique

All specimens were radiographed with three imaging modalities: Accu-I-Tomo (3DX) LCBCT (Morita), Digora® Optime (Soredex) image plate system and F-speed film (Eastman Kodak).

As regards the examinations with film and image plates, each mandibular specimen was mounted in a block of silicone paste and placed in the centre of a Plexiglas device to ensure a reproducible relationship between the X-ray unit, the object and the film/image plate. For each specimen, vinyl polysiloxane putty was adapted to the positioning device, and, while the putty was still soft, both detector and specimen were pressed into it. Once hardened, the putty allowed quick realignment of the specimen and detector.

F-speed films and blue SPPs, later to be scanned in a Digora® Optime scanner, were exposed using a Gendex Oralix DC (Gendex Dental Systems, Milan, Italy) dental X-ray unit operating at 60 kVp, 7 mA and 1.5 mm Al equivalent filtration. Film and SPP images were acquired at a focus–receptor distance of 25 cm. An optical bench was used to standardize irradiation geometry. A 20 mm thick soft tissue equivalent Plexiglas block was placed close to the mandible (in front of the tooth to be exposed) and facing the X-ray tube. Films and image plates were exposed for, respectively, 0.25 and 0.12 s. All films were developed using an AP-200 (PLH Medical, Watford, UK) automatic processor with a processing time of 6 min at 23.5℃. The Digora plates were scanned immediately after exposure using the Digora Optime scanner and the acquired images were saved uncompressed in a computer by means of Digora for Windows software.

The LCBCT images were taken at 80 kV and 1.5 mA. The filtration was 3.1 mm Al equivalent and the exposure time 17.5 s. For the LCBCT exposures, the Plexiglas block used as a tissue equivalent material during exposures of SPPs and films was replaced with a cylindrical one. This was machined to the same thickness as that used for image plate and film exposures and the mandibles were placed in the centre of this cylinder. A cylindrical form was preferred, because with the LCBCT technique image data are collected during a 360° rotation around the patient.[25]

With the LCBCT technique a cone-shaped X-ray beam, an image intensifier and a solid-state sensor are used for image capturing. Image data are collected during a single 360° rotation around the patient. After a reconstruction time of 85 s a cylindrical volume is created (height 30 mm, diameter 40 mm) from which tomographic layers (0.125–2 mm thick) can be obtained in any direction post exposure and simultaneously displayed in all three planes. Using 1 mm thick slices there are 30 images in the axial direction and 40 in the coronal and sagittal directions.

Image evaluation

Conventional film radiographs were mounted in non-transparent frames, placed on a light box and examined in a room where the light was dimmed. LCBCT and SPP images were viewed on a 15 inch high-resolution (super video graphics array) colour cathode ray tube monitor with a resolution of 1024 × 768 pixels (Philips Lightframe 107 P4, Philips Electronics, Eindhoven, The Netherlands) using the dedicated software of each digital system incorporated into the same computer. To ensure optimal visualization of the regions of interest, one of the investigators subsequently enhanced the original SPP and LCBCT images by manipulation of the brightness and contrast controls of the software interfaces of each system.[26] Pilot studies to determine optimal enhancement parameters across the different imaging modalities were carried out, and a panel of experts determined the optimal display parameters.[27] The images were then saved as uncompressed 8 bit tagged image file format (TIFF) files. Observers were not permitted to further enhance the digital images. All evaluators were equally inexperienced in assessing LCBCT images. They were therefore instructed about the image characteristics, drawbacks (artefacts) as well as interpretation of CBCT images using 15–20 different 2D slices a week before the evaluation sessions.

For each image modality all images were presented in a randomized order. A moderator presented each image for viewing and maintained proper random sequence order by means of a coding system. Three separate viewing sessions were held with at least 1 week in between to minimize viewer fatigue and to decrease the chance of recalling previous decisions on similar images. No time limit was set for the viewing procedure.

A periapical lesion was defined as a periapical radiolucency exceeding at least twice the width of the periodontal ligament space. Three radiologists and three endodontists with a mean age of 41.1 (range 29–56) years and mean clinical experience of 18.1 (range 8–32) years acted as evaluators and independently rated the presence/absence of periapical lesions using a five-grade scale: 1, definitely present; 2, probably present; 3, unsure; 4, probably absent; 5, definitely absent.

Images of 9240 different planes were obtained with the LCBCT system (30 axial + 40 sagittal + 40 coronal × 4 different acid durations × 21 apical areas). To avoid having the observers view all these images, a limited number of images were chosen for the scoring procedure. These were of layers in all three planes where the apex of each tooth was clearly seen plus images from the closest image layer in either direction. The observers did not give scores for each image, only for each periapical area. Thus, although 924 images were evaluated (84 conventional, 84 SPP and 756 LCBCT images), the number of scored periapical areas was 252: 84 for each image modality.

Statistical evaluation

Sensitivity and specificity were computed for each acid duration, where applicable. Negative (LR− = 1–sensitivity/specificity) and positive (LR+=sensitivity/1–specificity) likelihood ratios were calculated as well.

Receiver operating characteristic (ROC) analysis was carried out using data for each acid duration and each image modality by averaging the scores over all six observers. A computer program, ROCFIT (Charles Metz and colleagues, Department of Radiology, University of Chicago, January 1994), was used which fits a binormal ROC curve to ordinal category data (five category confidence ratings) by maximum likelihood estimations. The areas under the ROC curves (A_z) serve as a numerical estimate and summary measure of the diagnostic accuracy, ranging from 0 to 1.

A_z values were statistically compared using two-way ANOVA. Pairwise comparisons of imaging systems were done using the Mann–Whitney *U*-test. The differences among A_z values for different acid application periods were compared with Friedman and Dunn's tests. The level for statistical significance was set at $P<0.05$.

Cohen's kappa (κ) was used to measure the level of agreement between evaluators and the results interpreted using the following definitions: 0.01, poor; 0.01–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; 0.81–1.00, almost perfect.[28]

Results

The sensitivity, specificity, LR− and LR+ values for the different imaging modalities and acid durations are presented in Table 1. Overall, using LCBCT images, a significantly higher sensitivity and specificity than with both film and SPP images were found for all acid durations. As expected, a trend of increasing sensitivity for longer acid durations was indicated by the data. LR+ was highest for the LCBCT system, followed by SPP and F-speed films, while LR− was lowest for the LCBCT system.

The ROC curves as well as the individual and mean A_z values and standard deviations of the six observers are presented in Table 2.

The A_z values obtained from evaluations of LCBCT images were higher than those from SPP and film evaluations independent of acid duration (Table 2). Pairwise comparisons revealed that the difference was statistically significant only for 1 h of acid application when comparisons were made between LCBCT and the

Table 1 Sensitivity (SNT), specificity (SPF), negative likelihood ratio (LR−) and positive likelihood ratio (LR+) values for three different imaging modalities and three acid durations

	1 h acid application				*1.5 h acid application*				*2 h acid application*			
	SNT	*SPF*	*LR+*	*LR−*	*SNT*	*SPF*	*LR +*	*LR −*	*SNT*	*SPF*	*LR +*	*LR −*
Storage phosphor plate	0.73	0.67	2.19	0.40	0.74	0.67	2.21	0.18	0.94	0.67	2.83	0.08
Film	0.68	0.52	1.41	0.62	0.90	0.52	1.87	0.39	0.95	0.52	1.97	0.09
LCBCT	0.83	0.71	2.54	0.25	0.92	0.71	2.81	0.12	0.97	0.70	2.88	0.05

LCBCT, limited cone beam CT

film system ($P=0.02$), but for 1 h ($P=0.043$) and 1.5 h ($P=0.006$) of acid application when LCBCT was compared with the SPP system (Table 3). No significant difference was obtained between SPP and film images for any acid application duration ($P>0.05$). For the 2 h acid duration there was no significant difference between LCBCT and either of the two other image modalities ($P>0.05$) (Table 3).

Kappa analysis showed that agreement among evaluators' measurements for the detection of artificial periapical lesions ranged between slight and fair for SPP ($\kappa = 0.185$–0.346) and F-speed film ($\kappa = 0.178$–0.336) while it was between fair and moderate for LCBCT ($\kappa = 0.381$–0.581).

Discussion

The LCBCT system yielded a significantly higher sensitivity and specificity than both film and SPP modalities at all acid durations, and therefore proved to be the best for the detection of chemically created periapical lesions. The high LR+ and low LR− of the LCBCT system further contributed to this conclusion.

A_z values for the LCBCT system were higher for each acid duration than for film and phosphor plate systems, particularly for lesions produced by 1 h and 1.5 h of acid application and, thus, presumably smaller than those produced by longer acid durations. This suggests that a larger volume of bone loss is required before periapical radiolucency becomes evident on a film radiograph or digital image. This result can be theoretically expected since both analogue and digital periapical images provide only 2D views, resulting in bony changes becoming superimposed on the visually variable background of normal anatomy (structured noise). This is in contrast to limited cone beam radiography, in which the produced slices are free from image features from tissues on either side (back and front) of the lesion. This makes the mass difference between lesion and surrounding sound bone larger, contributing to a higher signal-to-noise ratio and higher image contrast. An additional advantage of limited cone beam CT is that it provides images in the coronal and axial planes, generally not seen with 2D radiographs of the premolar regions. Accordingly, in assessment of the thickness of the cortices, the location of the root apices, and loss of cancellous bone, the major limiting factors in 2D visualization of periapical lesions are not a problem with CBCT.[8,29]

Studies comparing the accuracy of conventional and digital intra-oral imaging systems as regards the detection of artificial bone lesions have found no significant difference was obtained among the areas under the ROC curves for various 2D imaging systems.[30–32] The finding of the present study, that no difference between digital and conventional intra-oral radiographs could be observed, is in accordance with previous reports.[22,33–35] However, it is not possible to directly compare our results with those from previous studies for a couple of reasons. First, most previous studies have used handpieces with burs to create artificial lesions. It is well known that this mechanical method creates defects with distinct borders that would improve lesion detection.[23,36,37] A few previous studies have used perchloric acid to create defects. Yet, there still are major differences between the methodologies of those studies and the present one.[23,38] One is the amount of acid applied and others are the location and duration of the acid application. Meier et al[38] used 0.10 ml of 70% perchloric acid and applied the acid to the tooth socket

Table 2 Areas under the receiver operating characteristic curves (A_z) and standard deviations (SDs) of six observers and three imaging modalities for each acid duration

	1 h acid application			*1.5 h acid application*			*2 h acid application*		
Observer	*SPP*	*Film*	*LCBCT*	*SPP*	*Film*	*LCBCT*	*SPP*	*Film*	*LCBCT*
1	0.69	0.59	0.74	0.72	0.79	0.89	0.88	0.91	0.86
2	0.74	0.59	0.74	0.74	0.64	0.89	0.79	0.74	0.98
3	0.69	0.78	0.97	0.59	0.83	0.89	0.81	0.79	0.79
4	0.64	0.67	0.83	0.69	0.74	0.83	0.79	0.76	0.86
5	0.81	0.57	0.76	0.74	0.74	0.85	0.88	0.73	0.91
6	0.71	0.67	0.91	0.76	0.74	0.91	0.86	0.79	0.93
Mean±SD	0.71±0.06	0.65±0.08	0.83±0.10	0.71±0.06	0.75±0.06	0.88±0.03	0.84±0.05	0.79 ± 0.06	0.89 ± 0.07

LCBCT, limited cone beam CT; SPP, storage phosphor plates

Table 3 Pairwise statistical comparison of A_z scores of three imaging modalities for each acid duration

	1 h acid	*1.5 h acid*	*2 h acid*
SPP — film	NS	NS	NS
SPP — LCBCT	S (P=0.043)	S (P=0.006)	NS
Film — LCBCT	S (P=0.02)	NS	NS

LCBCT, limited cone beam CT; NS, not significant; SPP, storage phosphor plates

from 2 h to 24 h, while Tirell et al[23] applied a drop of acid, without mentioning the exact amount, to the lateral surface of the cortical plate from 4 h to 96 h. In the present study, 0.05 ml of 70% perchloric acid was applied to the tooth sockets for 1–2 h. Meier et al[38] used double amount of acid and started with 2 h of application. Tirrell et al[23] applied the unknown amount of acid for at least 4 h.[23] Therefore, non-significant differences among A_z values of the above-mentioned studies can be expected owing to large lesions easily detectable with any imaging modality.

One of the major factors aiding the radiographic detection of a periapical lesion is size (*i.e.* the amount of bone loss compared with the dimensions of the jaw at the specific site) of the defect.[39–42] The differences found in regard to the defect size of the artificial lesions indicate that larger lesions were easier to detect than smaller ones. Since no difference was found among the A_z values of three different imaging modalities for 2 h of acid application (bigger lesions), no attempt was made to create larger defects. The detection of smaller lesions is a more challenging task since with large lesions signal strength would be so large as to permit easy detection with all imaging systems used in the present study.[27]

As already mentioned, the ability to detect a periapical lesion radiographically depends, among other factors, on the localization of the lesion within the bone. A lesion is radiographically visualized most readily when it is near or in the cortex and least likely when it is in the region of cancellous bone.[43] The defects in this study were created by applying acid at the bottom of the tooth sockets, *i.e.* defects were theoretically created in the cancellous bone. However, if the apex of the tooth is located at the interface of cortical and cancellous bone, a resorptive process may affect the cortical bone in an early stage.[44] In this case the detection of the lesion may be easier since cortical bone has more mineral content per unit volume.[8] No analysis was done to reveal the involvement of different bone compartments or the amount of mineral loss in the present study. The relatively low A_z values of SPP and film images, however, suggests either that the defects (at least for shorter acid durations) did not involve the cortical bone plate or that not enough mineral was lost (at least for shorter acid durations) to create contrast on the 2D radiographs.

There are many CBCT devices currently on the market that are designed for maxillofacial applications requiring larger fields of view (FOVs). However, it should be recognized that only devices providing smaller FOVs, coupled with a substantially higher resolution, are useful for dental applications requiring high levels of detail.[45] Improved pre- and post-operative diagnoses with high-resolution LCBCT in endodontic applications have already been demonstrated.[21,29] If further studies support the superiority of LCBCT in the early detection of changes in cancellous bone, it may be used as a complement to or even replacement for conventional radiography, considering the difficulties of detecting small bony lesions with the latter.[39,40,43] Clinically, this may mean that bone changes associated with systemic/pulpal pathosis may be detectable much earlier than hitherto possible. However, at present, there is no experimental evidence to support this generalization.

Comparison of the imaging systems demonstrated a statistically significant difference between SPP and film, on the one hand, and LCBCT images, on the other, for 1 h of acid application. However, when lesions became larger, with 1.5 h of acid application, no difference was found between LCBCT and film images, whereas a statistically significant difference remained between SPP and LCBCT. The relatively better performance of film-based images over SPPs might indicate that the observers were biased towards this imaging modality for a number of reasons. Observers were more familiar with the film medium, since radiographic interpretation has traditionally been taught with a film-based image as the standard. Resolution of the digital images may be another factor that can affect diagnosis. The spatial resolution of the Digora Optime system, the new version of Digora, was approximately 10–12 lp/mm, while this value is at least 20 lp/mm for F-speed film.[46]

It has been hypothesized that digital enhancement of images would increase the true-positive diagnosis while decreasing the true-negative diagnosis.[47] For this reason the images were enhanced by one radiologist to a subjectively optimal level before being presented to the observers. The selection of the appropriate algorithm requires a balanced knowledge of mathematical theory, optics, computer technology and common sense.[48] Considering these factors along with the results of many previous studies[31,43,46,47] finding no improvement in diagnosis with image enhancement, the observers were not given the option to perform any image enhancement on their own which might have ended in a variety of different digital images.

This study presented the first opportunity evaluating the observer performance for interpretation of artificial periapical lesions using LCBCT. Observers in this study had long experience of film and digital radiographs, but were unfamiliar with cone beam CT images. However, it is noteworthy that interobserver agreement was higher for LCBCT, which indicates a consistent level of performance for this advanced imaging modality.

LCBCT imaging has several advantages over conventional radiography. The axial and coronal views are of particular value, since they cannot be obtained with conventional radiography. One advantage, not evaluated in this study, is the ability to localize a lesion accurately and true to its original size.[49] In addition, the image field size of the cone beam machine used is 30 × 40 mm, that is practically the same as that of a no. 2 dental film/plate (30 × 41 mm). Therefore, there is no difference between these detectors as regards the number of tooth surfaces that can be displayed. The effective dose per exposure has been reported to be the same as that generated by rotational panoramic radiography or a few intra-oral radiographs.[50]

In conclusion, observers were better at detecting chemically induced periapical lesions of limited size by means of LCBCT images than using conventional film and digital images.

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