doi:10.1111/j.1365-2591.2007.01204.x

Imaging of root canal fillings: a comparison of subjective image quality between limited cone-beam CT, storage phosphor and film radiography

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Abstract

Soğur E, Baksı BG, Gröndahl H-G. Imaging of root canal fillings: a comparison of subjective image quality between limited cone-beam CT, storage phosphor and film radiography. *International Endodontic Journal*, **40**, 179–185, 2007.

Aim To compare the subjective quality of limited cone-beam computed tomography (LCBCT), storage phosphor plate (SPP) and F-speed film images for the evaluation of length and homogeneity of root fillings.

Methodology Root canals of 17 extracted permanent mandibular incisor teeth were filled. With the teeth placed in their jaws, images were obtained with Accu-I-Tomo LCBCT, Digora® Optime image plate system and F-speed film using exposure parameters yielding 'clinically' acceptable density and contrast. Three radiologists and three endodontists independently rated the quality of all images in respect to homogeneity and the length of root fillings using a 3-graded scale. Evaluations were undertaken in two sessions. In the first, the coronal LCBCT images were not included. In the second, both coronal and sagittal LCBCT images were rated along with F-speed film and SPP images. Results were compared using the Friedman test ($P < 0.05$). Pair-wise comparisons of systems were completed using the Wilxocon signed-ranks test ($P < 0.05$). Kappa was used to measure interobserver agreement.

Results Digora images were rated superior, consecutively followed by F-speed films and LCBCT images, for the evaluation of both homogeneity and length of root fillings in both the evaluation sessions ($P < 0.05$). Kappa ranged from slight to moderate for the length evaluation of root fillings and from poor to fair for the evaluation of homogeneity of root fillings.

Conclusion Image quality of storage phosphor images was subjectively as good as conventional film images and superior to LCBCT images for the evaluation of both homogeneity and length of root fillings in single-rooted teeth.

Keywords: digital volumetric tomography, endodontic treatment, image quality, photostimulable storage phosphor system.

Received 9 June 2006; accepted 21 August 2006

Introduction

Careful assessment of the root canal system based on high quality radiography is a prerequisite for all stages of root canal treatment from initial diagnosis through the monitoring of treatment (Lavelle 1999, Wallace *et al.* 2001). As increasing demands on better image quality in endodontic practice, there is a growing need to measure and document image quality at all steps from acquisition through display where efficiency and reliability are particularly important (Samei *et al.* 2004).

Studies have compared the quality of digital images with conventional radiographs for working length determination, detection of periapical lesions and visualization of the root canal anatomy (Kullendorff *et al.* 1997, Sullivan *et al.* 2000, Naoum *et al.* 2003,

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Woolhiser *et al.* 2005). However, no digital system has shown better results in those aspects than conventional film imaging. Recent studies have demonstrated that digital image quality approaches that of conventional film images, but only after the application of image processing algorithms (Li *et al.* 2004, Kositbowornchai *et al.* 2006). Although the continuing development of digital radiography and image processing has created new opportunities for image quality improvement, it can do little to decrease the superimposition of overlying structures that obscure the object of interest. As clinical radiographs are only two-dimensional (2D) reproductions, the radiographic monitoring of root canal treatment is challenging because of the difficulties in distinguishing features superimposed onto each other. The problem inherent to 2D imaging can result in difficulties in endodontic practice when determining the spatial relationship of multiple canals in the same root as well as the ideal depth of instrumentation (Barton *et al.* 2003). Obtaining radiographs with different horizontal and/or vertical angulations may provide additional information about the root canal system, but does not always suffice. In addition, it means repeated exposures of the patient (Naoum *et al.* 2003). Therefore, there is a need for radiographic tools that may provide more accurate 3D information in both pre- and post-treatment assessment of root canal systems.

In 2000, limited cone-beam computed tomography (LCBCT) was introduced allowing for 3D imaging of dento-alveolar regions at a lower radiation dose and cost compared with conventional computed tomography (CT) (Arai *et al.* 1999). Reports about its use for several dental applications have been published (Ziegler *et al.* 2002, Hatcher *et al.* 2003, Heiland *et al.* 2004, Tsiklakis *et al.* 2004, Hilgers *et al.* 2005, Walker *et al.* 2005). However, there is no published data comparing digital volume tomography with conventional film or storage phosphor images for the evaluation of the quality of root fillings.

The aim of this preliminary study was to compare the subjective image quality of LCBCT with storage phosphor plate (SPP) and F-speed film images for the evaluation of length and homogeneity of root canal fillings.

Materials and methods

Specimens

Ten dry human mandibular specimens were selected on the basis that they contained incisor and canine teeth with no restorations, no previous root fillings and no periapical pathosis. Seventeen anterior teeth fulfilling the criteria were extracted with surgical elevators and forceps applying a minimal amount of force. After visual inspections ruled out root or bone fractures, the teeth were repositioned to their sockets. Radiographs were taken to confirm proper repositioning and reconfirm the absence of apical pathosis.

Root canal treatment

Standard access cavities of the extracted teeth were prepared using a water-cooled diamond fissure bur in a high-speed hand piece. Gates-Glidden drill numbers 2 and 3 (Dentsply Maillefer, Ballaigues, Switzerland) were used to enlarge the coronal part of the root canals. Working length was determined visually by passing size 10 K-file just through the apical opening and then subtracting 1 mm from this length. Root canal preparations were performed using a step-back technique with H-files. The master apical file was size 30 and step-back was performed in 1 mm increments until a size 60. Between each instrumentation, 1 mL of 2.5% NaOCl was used for the irrigation and a total of 10 mL of NaOCl was utilized in each canal. After the final instrumentation, root canals were filled with a lateral compaction technique using standard size 25 gutta-percha cones and Diaket (3M Espe, Seefeld, Germany) as the root canal sealer. Excess gutta-percha was removed with a hot instrument at a level 1 mm apical to the canal orifices. The cavities were restored with bonding (Adper Single Bond, 3M Espe, St Paul, MN, USA) application and resin composite restorations (Filtek Z250, 3M Espe).

Radiographic technique

Each mandibular specimen was mounted in a block of silicone paste and placed in the centre of a plexiglass device to ensure a reproducible geometry between the X ray unit, object and film/sensor. For each specimen, vinyl polysiloxane putty was adapted to the positioning device, and whilst the putty was still soft, the SPP was pressed into it. Once hardened, the putty allowed quick realignment of specimen and SPP and F-speed film. A plexiglass block with a thickness of 15 mm was placed between the radiographic source and specimen to simulate soft tissue.

All films and sensors 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 at a focus–receptor distance of 25 cm. An optical bench was used to standardize irradiation geometry. Radiographic images of experimental teeth were obtained with F-speed (Eastman Kodak, Rochester, NY, USA) films and Digora® SPP (Soredex Corporation, Helsinki, Finland). F-speed films and SP plates were exposed with respectively 0.25 and 0.12 s which had been shown to yield 'clinically acceptable' density and contrast. All films were developed using an AP-200 (PLH Medical Ltd, Watford, UK) automatic processor with a processing time of 6 min at 23.5 °C. The Digora plates were scanned immediately after the exposure using Digora Optime scanner. Acquired images were saved uncompressed by means of Digora for Windows software.

The LCBCT images were taken using Accu-I-Tomo (3DX) LCBCT (Morita Co. Ltd, Tokyo, Japan) at 80 kV and 1.5 mA. The filtration was 3.1 mm Al equivalent and the exposure time 17.5 s. Above mentioned thick soft tissue equivalent material was placed just in front of the test teeth of the mandibles during the exposures. Its location close to the teeth ensured that it was within the radiation beam during the entire exposure. In LCBCT, a cone shaped X ray beam, an image intensifier and a solid-state sensor are used for image capturing (Mozzo *et al.* 1998). Image data are collected during a single 360 ° rotation round the patient. After a reconstruction time of 85 s a cylindrical volume is created (height of 30 mm, diameter of 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

The processed radiographs were placed on a light box and examined in a room where the light was dimmed. Similarly, both SP and LCBCT images were analysed with the software programs provided by each system on a 15-inch super VGA computer monitor (LiteOn, Guang Dong, China) in a darkened room to minimize glare.

Three radiologists and three endodontists independently evaluated the images from all modalities and rated the image quality of root fillings in the same random order under the same viewing conditions. Evaluations were completed in two sessions. In the first one, coronal 3DX images were not included. In the second one, both coronal and sagittal 3DX images were rated along with F-speed film and SPP images. Sixty-eight images (17 conventional, 17 SPP and 34 3DX images) were assessed by each evaluator.

The evaluators ranked the images of the jaw specimens for subjective diagnostic quality with regard to the length and homogeneity of the root canal fillings, using a 3-graded scale ranging from one (desirable diagnostic quality), two (just acceptable diagnostic quality) to three (undesirable diagnostic quality). The evaluators used the same 3-graded scale on the 2nd evaluation session. However, the combination of sagittal and coronal 3DX images received a single quality score. The evaluators were directed to concentrate on the visibility of the contours of the apical end of the root filling, its length and uniformity, and its adaptation to the lateral canal walls (homogeneity) rather than on the aesthetics of the image. Desirable image quality was ascribed to images demonstrating a clear demarcation of root filling length and homogeneity. Just acceptable image quality described images useful for interpretation of the periradicular bone but not for evaluating root filling length and homogeneity. Undesirable image quality described an image useless in all these aspects. No time limit was set for viewing the images.

Statistical analysis

Comparison of the conventional film radiographs and digital images of two different techniques was performed using the Friedman test, with a significance level set at $P = 0.05$. Pair-wise comparisons of systems were completed using the Wilxocon signed-ranks test ($P < 0.05$). To compare the 1st and 2nd evaluations of imaging modalities the Wilcoxon signed-ranks test was used. The Cohen's Kappa test was employed to measure the level of agreement between evaluators and the results were 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 (Landis & Koch 1977).

Results

Table 1 shows the sum of image quality scores for both homogeneity and length of root fillings for each imaging modality. According to the 3-graded scale images with the best quality were ascribed the lowest scores (one and two). Hence, the lowest sum of these scores was obtained by the imaging system that, on average, was judged subjectively best (Table 1). In both of the evaluation sessions, Digora images received the

Table 1 Total sum of image quality scores for the images produced using different imaging systems for the evaluation of length and homogeneity of root canal fillings

Image system	Evaluation session	Sum of ratings (length)	Sum of ratings (homogeneity)
Digora	1st	163	172
	2nd	182	175
Film	1st	177	180
	2nd	193	188
LCBCT	1st	272	260
	2nd	237	249

LCBCT, limited cone-beam computed tomography.

lowest sum both for the evaluation of homogeneity and length of root canal fillings ($P < 0.05$), consecutively followed by F-speed films and cone-beam (3DX) images (Table 1). Pair-wise comparisons of the imaging systems showed no statistically significant difference between observers' ratings for F-speed films and Digora SPP images in either of the evaluation sessions ($P > 0.05$). However, the differences between film and 3DX and between Digora and 3DX images were statistically significant ($P < 0.05$). The difference between the ratings of the two evaluation sessions was significantly different only for the 3DX images ($P < 0.05$) indicating that the addition of coronal images slightly improved the observers' ratings. It did not, however, result in a different ranking order for this imaging modality.

Agreement amongst endodontists' and radiologists' measurements for the evaluation of homogeneity of root fillings ranged between poor to fair for Digora ($\kappa_{\text{min–max}} = 0.009–0.354$), poor to moderate for F-speed film ($\kappa_{\text{min–max}} = 0.013–0.422$) whilst it was between slight to fair for 3DX ($\kappa_{\text{min–max}} = 0.018–0.354$). On the other hand, Kappa scores for length evaluation ranged between slight to moderate for both Digora ($\kappa_{\text{min–max}} = 0.011–0.609$) and F-speed film ($\kappa_{\text{min–max}} = 0.014–0.449$) but slight to substantial for 3DX ($\kappa_{\text{min–max}} = 0.162–0.776$) (Table 2).

Discussion

Developments in computer technology have contributed to the development and widespread use of digital intraoral radiography. The rate at which new technologies enter the marketplace and the limited amount of knowledge regarding the relationship between physical characteristics and clinical outcomes, sustain a high demand for diagnostic efficiency testing (Ludlow *et al.* 2001). Although physical and technical properties of new systems are more amenable to measurement and quantification than processes involving human behaviour, they alone are insufficient to predict the diagnostic performance of an imaging system because of the poor correlation between fundamental physical factors and image quality in clinical terms (Martin *et al.* 1999, Borg *et al.* 2000). It has been demonstrated previously that the process of evaluating image quality must include not only physical measurements, but also performance measures that include psycho-physical, environmental, and system considerations. As there is no direct correspondence between physical properties and clinical diagnostic outcomes, it was reported that analyses combining the effect of physical parameters influencing the image quality are mandatory for the testing of imaging efficiency (Fryback 1983, Fryback & Thornbury 1991). This approach was found to be better than most technical evaluation methods and it has been validated in many previous studies (Vucich 1979, Borg & Gröndahl 1996, Borg *et al.* 2000, Kaeppler *et al.* 2000, Kitawaga *et al.* 2000). It was stated that this would facilitate the clinical extension of scientific outcomes and provide data to drive the development of new technologies based on diagnostic needs (Vucich 1979). Månsson (2000) implied that the results of such studies would help radiologists to calibrate his/her image viewing.

In general, the results of this subjective evaluation indicate that SPP and F-speed film images were perceived as superior to the corresponding cone-beam

Table 2 The mean Kappa values of eight observers ± standard deviation (SD) of values for two different evaluation sessions (1st and 2nd) for the evaluation of both length and homogeneity of root canal fillings using images of Digora storage phosphor plate system, F-speed film and limited cone-beam computed tomography (LCBCT) system. Minimum (Min) and maximum (Max) values indicate the range of Kappa values amongst eight observers

	Digora		Film		LCBCT	
	Mean ± SD	Min–Max	Mean ± SD	Min–Max	Mean ± SD	Min–Max
Homogeneity 1st	0.149 ± 0.13	0.009–0.354	0.114 ± 0.12	0.013–0.354	0.128 ± 0.13	0.033–0.331
Homogeneity 2nd	0.097 ± 0.06	0.090–0.190	0.128 ± 0.15	0.014–0.422	0.129 ± 0.15	0.018–0.354
Lenght 1st	0.248 ± 0.17	0.011–0.609	0.183 ± 0.16	0.014–0.426	0.333 ± 0.16	0.162–0.776
Lenght 2nd	0.178 ± 0.14	0.024–0.457	0.118 ± 0.11	0.181–0.449	0.199 ± 0.12	0.181–0.449

CT images for evaluating both homogeneity and length of root fillings.

Pixel size is an important parameter in SP systems because it directly influences the spatial resolution (Chotas *et al.* 1993, Hildebolt *et al.* 1994). The spatial resolution of Digora fmx system – older version of Digora – was approximately 7–8 lp mm^{-1}, whilst this value is at least 20 lp mm^{-1} for F-speed film (Farman & Farman 1999). With the introduction of Digora Optime, spatial resolution of the SP plates rose to 12.5 lp mm^{-1}, approaching that of conventional films. This may be one of the reasons for the equivalent predilection of observers to the SPP and film images compared with the 3DX images that have a spatial resolution of only about 2 lp mm^{-1} (Accuitomo brochure, 2005, http://www.jmoritausa.com/marketing/pdf/3D_AccuitomoJan2005.pdf). However, there is little meaning in comparing spatial resolution of imaging systems based on entirely different principles.

Observers reported that the fillings could be seen true to scale and without overlay or distortion in the Accu-I-Tomo images. On the other hand, they also noted the presence of streaking artifacts (because of the gutta-percha and sealer) compromising the quality of those images as regards root filling evaluations. Kobayashi *et al.* (2004) reported that one of the drawbacks of cone-beam images was its low contrast resolution. It is also known that noise increases with decreasing voxel size (Araki *et al.* 2004). Further, the LCBCT device used in the present study uses an image intensifier tube, known to produce images with more noise than flat panel detectors (Scarfe *et al.* 2006) as in a later version of the Accu-I-Tomo cone-beam unit. Accordingly, it may be possible to postulate that image noise was higher in Accu-I-Tomo images than in SPP or film images. This may be one of the major reasons why 3DX images received the lowest quality scores as regards evaluation of quality of root fillings where subtle details such as the apical ends and voids along the fillings are particularly important. Radiographic visualization is influenced by a number of physical, technical and psychophysical factors. Another reason for the observers to subjectively prefer the Digora Optime and film images may be their familiarity with the SPP and film images. This might induce a high level of diagnostic confidence independent of the inherent properties of the different type of images.

Most studies evaluating the quality of root fillings have looked at the diagnostic efficiency of sensor systems versus that of conventional radiographic films (Pauzaras *et al.* 2000, Wallace *et al.* 2001, Akdeniz & Soğur 2005). The present study is the first to include digital volumetric tomography in a subjective evaluation of image quality. Therefore, results of previous studies comparing the image quality of different radiographic systems cannot be exactly related to the present findings as the combinations of imaging systems used are different.

The image field size of the 3DX system used is 30×40 mm, i.e. practically the same as that of a size 2 dental film and SPP (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 about two intraoral radiographs (Iwai *et al.* 2000) but more studies are required to establish whether this relationship can be considered valid.

The advantage of 3D-imaging of 3D anatomic structures can be easily appreciated given that methods providing sufficient resolution can be used. From a practical point of view 3D high resolution imaging of dento-alveolar structures is no more difficult than intraoral radiography. Cone-beam CT by which limited volumes are examined may be an alternative to intraoral imaging of multi-rooted teeth when the latter does not allow each root to be viewed separately. For single-rooted teeth conventional intraoral imaging remains the technique of choice when evaluating quality of root fillings.

Conclusion

Image quality of Digora Optime SPP images was subjectively as good as conventional film images and superior to LCBCT images for the evaluation of both homogeneity and length of root fillings in single-rooted teeth.

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