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ORIGINAL ARTICLE

LCD and CRT display of storage phosphor plate and limited cone beam computed tomography images for the evaluation of root canal fillings

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Abstract The aim was to compare quality of liquid crystal display (LCD) and high resolution cathode ray tube (CRT) screens for the evaluation of length and homogeneity of root canal fillings in storage phosphor plate (SPP) and limited cone beam computed tomography (LCBCT) images. Endodontic treatment was performed to 17 extracted permanent lower incisor teeth. Images of each tooth positioned in a dried mandible were obtained with Digora® SPP and Accu-I-Tomo LCBCT systems. Six observers scored the quality of all images on CRT and LCD screens. Results were compared using McNemar's and Cochran's *Q* tests ($p<0.05$). The differences among the LCBCT and SPP images were determined by binomial test. No significant difference was found between ratings of CRT and LCD displays ($p>0.05$). Agreement among observers' scores was higher with CRT display. Within the limits of this ex vivo study, differences between LCD and CRT monitors for the evaluation of root canal fillings are clinically insignificant independent on whether conventional radiographs, captured by means of image plates, or cone beam images are being displayed.

Keywords Display · Endodontic treatment · Photostimulable storage phosphor system · Tomography · Digital volumetric · Ex vivo

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Introduction

Desktop computers and cathode ray tube (CRT) monitors are currently used in diagnostic radiology. Due to their size and problems of light reflections in CRT screens, the use of laptop computers may be an alternative. Their liquid crystal displays (LCDs) have essentially all the attributes of high quality CRT displays [1, 4, 13]. Studies comparing the image quality provided by different display systems [5, 19, 22] have mostly dealt with the physical characteristics of CRT monitors or different types of projectors [5, 22]. Studies of the diagnostic accuracy of digital radiographic systems for various dental tasks are confined only to CRT monitors because of their predominant use [1, 4, 13]. The few studies that have compared the effect of display monitor on dental digital radiographs have mainly focused on the detection of dental carious lesions [1, 4, 13]. No studies have compared the performance of different display devices for the evaluation of root canal fillings. Moreover, no study has used images produced by limited cone beam computed tomography (LCBCT) for the evaluation of different displays.

Studies that compared two displays of different types of dental images indicated equal performances for film and digital images [1, 15]. Review of medical literature revealed similar results for CRT and LCD displays of various types of images of either low or high contrast medical pathologies as well [11, 12]. Looking at the identical methods and complementary results of the above-mentioned studies other than repeating identical comparisons of film and digital images, one frequently used (intra-oral digital) and one new and emerging dental imaging technique (LCBCT) that is believed to become a complement or even replacement to conventional radiography for diagnosis in endodontics was preferred for comparison of different displays.

Therefore, the aim of this study was to compare the subjective image quality of cathode ray tube monitor and laptop displays of LCBCT and storage phosphor plate (SPP) images used for evaluating length and homogeneity of root canal fillings.

Materials and methods

Specimen

Ten dry human mandibles containing unrestored incisor teeth with no evident periapical pathosis were used. Seventeen teeth were extracted from the jaw specimens using surgical elevators and forceps applying a minimal amount of force. After visual inspection to ensure absence of root or bone fractures, the teeth were repositioned to their sockets. Each mandibular specimen was mounted in a block of silicone paste and an SPP was pressed into this material while still soft. Once hardened, it allowed quick realignment of specimen and SPP plate. A plexiglass block with a thickness of 15 mm was used between the radiographic source and specimen to simulate soft tissue during the exposure of SPPs [2, 7]. However, during the LCBCT exposures, the mandibles were placed in the center of a circular plexiglass soft tissue equivalent material with the same thickness because of 360° rotation technique of the system [20].

Root canal treatment

Standard access cavities of the extracted teeth were made using a water-cooled diamond fissure bur in a high-speed hand piece. Gates–Glidden drills #2 and #3 (Maillefer, Ballaigues, Switzerland) were used to enlarge the coronal part of the root canals. Working length was determined visually by passing #10 K-file just through the apical opening and then 1 mm was subtracted from this length. Root canal preparations were performed using step-back technique with H-files. While master apical file was #30, step-back was performed in 1-mm increments until a size of #60. Between each instrument, 1 ml of 2.5% NaOCl was used for irrigation. A total of 10 ml of NaOCl was utilized in each canal. After instrumentation, root canals were obturated with lateral compaction technique using standard #25 gutta-percha cones and Diaket (3M Espe, Seefeld, Germany) as root canal sealer. Excess gutta-percha was cut with a hot instrument from 1 mm down the canal orifices. The cavities were then restored with bonding application (Adper Single Bond, 3M Espe, St. Paul, MN, USA) and a resin composite restoration (Filtek Z 250, 3M Espe, Seefeld, Germany).

Radiographic technique

Storage phosphor plates placed at a distance of 30 cm from the X-ray focus were exposed with an X-ray unit (Oralix DC, Gendex Corp, Des Plaines, IL, USA) with 1.5 mm Al equivalent total filtration. Operating at 60 kVp, 7 mA, and an exposure time of 0.12 s, “clinically” acceptable density and contrast were obtained after scanning in a Digora Optime® scanner (Soredex Corporation, Helsinki, Finland). Acquired images were saved as TIFF files by means of Digora for Windows software (Fig. 1b).

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 s. In the used version of the Accu-I-Tomo unit, an image

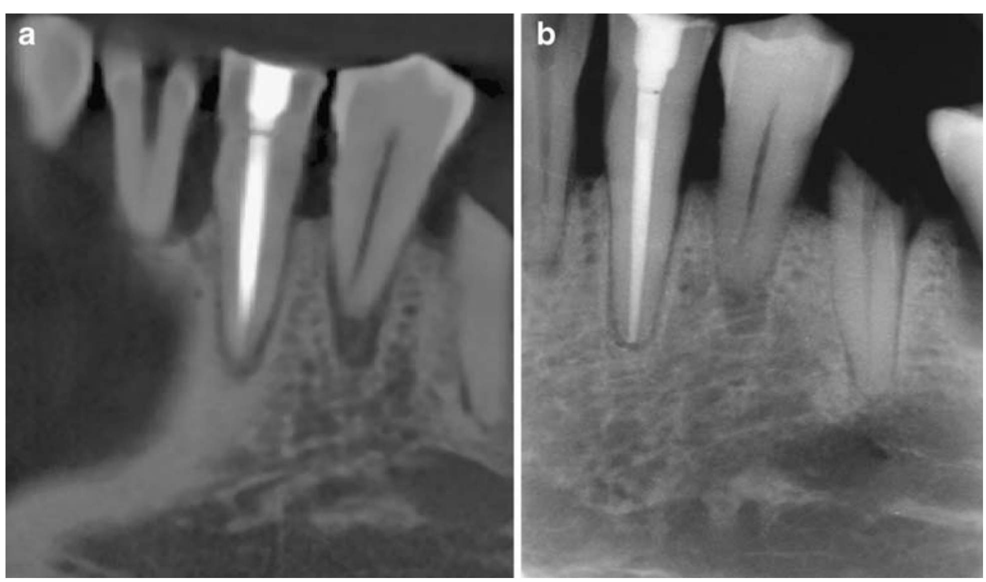


Fig. 1 **a** Sagittal LCBCT image **b** SPP image; SPP and sagittal images of the LCBCT systems showing identical incisal root filling

intensifier and a solid-state sensor were used for image capturing [16]. 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 three planes at right angles to each other. In order to rule out possible bias regarding the different type and number of images produced by two imaging systems, only sagittal images of the limited cone beam system (Fig. 1a) were included to the evaluation.

Image evaluation

All SPP and LCBCT images were transferred to an IBM-compatible personal computer (Philips Lightframe 107 P4, Philips Electronics, Belgium, Netherlands) and a laptop computer (Toshiba Satellite A60, Toshiba Corporation, Tokyo, Japan). The former type of computer was equipped with a high resolution (XGA) 17-in. flat desktop monitor and the latter type of computer with a 15-in. active matrix LCD display (XGA) without protective glass or additional antiglare coating. Both displays used the same ATI Radeon™ 9800 XT, 256 MB graphics card (ATI Technologies Inc., Ontario, Canada). For both computers, the screen resolution and the color display were set at 1,024× 768 pixels and 8-bit depth. Both screens had identical dot pitch (0.28) and luminance (300 cd/m^2) values.

Two image modalities (SPP and LCBCT) and two display formats (LCD and CRT) were, therefore, available for the evaluation. To minimize observer learning effects, images were displayed in a preset randomized order.

Three radiologists and three endodontists independently scored the image quality with respect to evaluations of root canal fillings in images displayed on CRT and LCD screens in a random order. Each evaluator assessed 34 images (17 SPP and 17 sagittal LCBCT images), first in one display mode and at least 1 week later in the other one. The order was different for the different evaluators who first scored the images with regard to their ability of being used for assessing root filling length and then for homogeneity of the root canal fillings, both times assigning 0 to images of unacceptable quality and 1 to those of acceptable quality.

The evaluators were directed to concentrate on the possibilities of evaluating the contours of the apical end of the root canal filling, its length and uniformity, and its adaptation to the lateral canal walls (homogeneity). Acceptable image quality was ascribed to images clearly demonstrating root filling length and homogeneity and unacceptable quality to those poorly visualizing those details. During the observation sessions, observers were constantly reminded about evaluating the quality of the display and not the quality of the root canal fillings. No time limit was set for viewing the images which was done in a darkened room at a viewing distance of 50 cm from the screens, the backgrounds of which were set at black.

Statistical analysis

Observers' scores for the two different display modalities for each imaging system were compared using McNemar's test, with a significance level set at $p=0.05$. Cochran's Q was used to determine the homogeneity among observers' scores. The differences between the scores of LCBCT and SPP images were determined by binomial test. Each test was performed separately both for length and homogeneity evaluations.

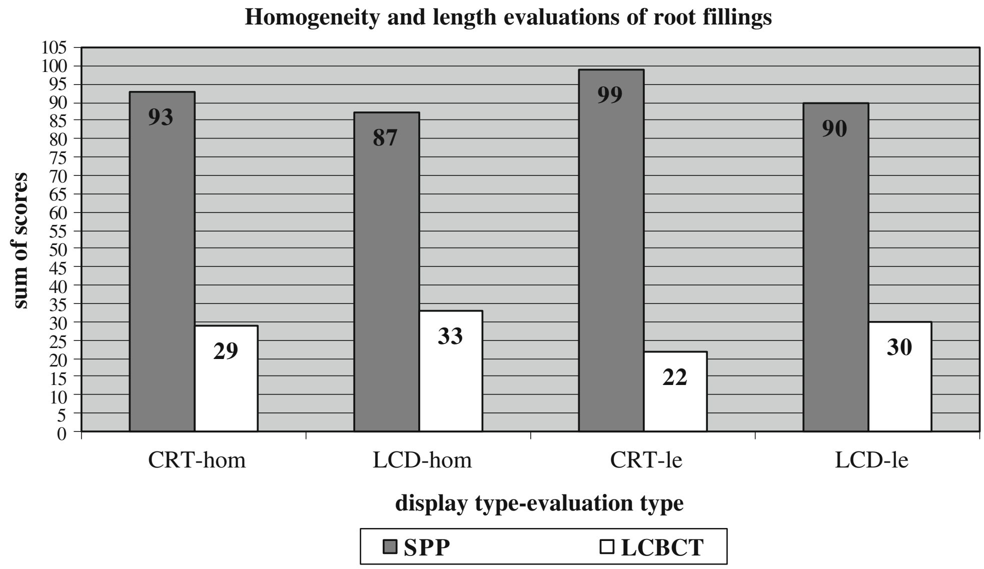
Results

Figure 2 shows the total sum of ratings for two different display devices when evaluating homogeneity and length of root fillings in images from two imaging systems. The highest sum of these scores was obtained by the display system that, on average, was judged subjectively best. LCD display of SPP images received scores 87 and 90 for homogeneity and length evaluations, respectively, while CRT display received scores 93 and 99. When using the LCD display for LCBCT images, scores 33 and 30 were given for the possibilities of rating homogeneity and length of root fillings as opposed to 29 and 22 for the CRT display (Fig. 2). When each imaging system is evaluated in itself, no statistically significant difference was found between total ratings of CRT and LCD displays for the evaluation of homogeneity or length of root canal fillings for either of the imaging systems ($p>0.05$). However, the display quality scores of the six observers for SPP and LCBCT images were significantly different. SPP images received the highest scores on both displays ($p<0.05$; Fig. 2). Although no significant difference was found between the total scores given to the two displays, Cochran's Q test demonstrated high concordance among the observers' scores for the CRT display but significant incongruity among the observers' scores for the LCD display ($p<0.05$).

Discussion

Increasing demands on better radiographic image quality in endodontic practice strengthen the need to measure and document image quality at all steps from acquisition through display [18]. Not only technological advancements in digital radiography but also advancements in computer systems warrant continuous testing of imaging systems' performance for separate dental tasks [21].

Fig. 2 Total sum of scores of six observers for length (*le*) and homogeneity (*hom*) evaluations of root canal fillings on *CRT* and *LCD* for images obtained using *SPP* and *LCBCT* images



Display of radiographic images using CRT or LCD technology is rapidly becoming more common within dental radiography. The diagnostic performance of imaging modalities that rely on display devices for interpretation is affected by the quality of the latter technology. The two monitors tested in this study were chosen on the basis of commercially available monitors recommended for dental digital imaging systems and owing to their similar physical properties (same resolution, dot pitch, and gray scale display) which were adequate for valid diagnosis. Accordingly, no significant difference was found between the diagnostic performances of two different displays when used for evaluating homogeneity and length of root canal fillings. This result is compatible with the results of previous studies showing that the type and physical characteristics of the monitors did not alter diagnostic accuracy of dental carious lesions [1, 13].

The standard approach for measuring the trait of interest in diagnostic radiology is the use of a continuous rating scale. However, sooner or later, for practical use, we need to dichotomize our alternatives so that we can classify subjects as “diseased” or “healthy”. There are numerous yes-and-no problems in both dental and medical practice. Continuous scale, although regarded as a more sensitive approach, was demonstrated to be less robust than an analysis based on a choice of a dichotomous trait [6] and accordingly used as the method of choice in many previous [3, 23] and recent [14, 21] radiology studies. During the decision-making process of which monitor to pick for an endodontic and/or radiology clinic, one must choose either the one or the other; in other words observers were asked to make one or the other diagnostic decision; therefore, dichotomous scale was preferred as the scoring method in the present study.

The development of LCBCT is a significant step toward improved preoperative and postoperative diagnosis in endodontics as a complement or a substitute to conventional radiography [8]. In endodontic research, it has been used for the evaluation of root canal anatomy, for the assessment of root canal morphology after instrumentation, and for the investigation of endodontic obturation [17, 20]. The advantage of the elimination of overlying structures has already made this technology a commonplace in endodontic clinics. Accordingly, LCBCT images were included in the present study.

Resolution of the Digora Optime SP plates is 12.5 lp/mm, while resolution of the LCBCT image is given as 2 lp/mm at a modulation transfer function (ability of an imaging system to reproduce or record information) of 10% (http://www.jmoritausa.com/marketing/pdf/3D_AccuitomoJan2005.pdf). This value, although lower than that of SPP images, still yields high resolution 3D images because of the decrease of anatomic noise from surrounding structures. The higher resolution of SPP images may be the reason for the higher scores given to this image modality. Moreover, the presence of striking artifacts (due to the gutta-percha and sealer) in LCBCT images, compromising image quality, may have an effect on the predilection of observers to SPP images in either display.

It was the finding of the present as well as a previous study that artifacts from root canal fillings, to some extent, can be quite disturbing [20]. However, since the primary aim of the present study was to compare the quality of two different displays but not the quality of root fillings, artifacts from the fillings were not considered a problem as long as identical images appeared on both displays. Nonetheless, when observers are forced to make a preference between two types of images, SPP images may be the image of choice on both displays owing to its higher image quality. Although subjective ratings of LCBCT images received inferior ratings on both displays in this study, in a study by Holberg et al., comparison of the image quality of a CBCT and a dental CT demonstrated practically no metal artifacts around metal filings and implants when CBCT is employed [10]. Thus, CBCT is particularly recommended if metal is present. It is also known that LCBCT technology is used to detect fractures that occur in roots with metal root canal posts [8]. Besides, image quality of the LCBCT used in the present study (technology with an option to select the region of interest in accordance with clinical demands) was proved to surpass the image quality of LCBCT machines that acquire data from a larger volume [9]. Recently, flat panel detector-based CBCT scanners were introduced to the market as well as manufacturers' artifact suppression algorithms, allowing a further decrease in level of artifacts.

Observers seemed to be more comfortable evaluating root canal fillings with CRT display than with the LCD, judging from the better homogeneity among observers' scores when evaluating CRT images. Radiographic visualization is influenced by a number of physical, technical, and psychophysical factors. Since the technical qualities of both displays used in the present study were similar, the reason for the observers to subjectively prefer the CRT display may be their familiarity. Observers were more familiar with CRT display of images, which the digital radiographic interpretation has traditionally been taught with CRT monitors as the standard. This might induce a high level of diagnostic preference and/or habit independent of the inherent properties of different types of displays. Although no significant difference was obtained between CRT and LCD displays of two different image types, by looking at the Fig. 2, it can be noted that SPP images generally seem to score better on CRT compared to LCD, whereas LCBCT images scored slightly better on LCD display. However, due to the difficulties in obtaining cadaver mandibles, the sample size of this study was not high enough to reveal the significance (if any) of this tendency.

It is generally accepted that due to its excellent visual qualities, active matrix liquid crystal displays are the choice for any imaging system. However, with regard to evaluation of root canal fillings, no benefit, from a quality point of view, was found with the use of LCD monitors. However, this principal outcome that was based solely on inter-observer reproducibility may be considered as the limitation of this study. On the other hand, since all observers in the study were educators of dental radiology who were meticulously instructed about the scoring process, no assessment of intra-observer agreement was done. In addition, intra-observer agreement is a particular requirement when continuous scale for rating is used (when there are three to five scores and accordingly possibility for higher margin of error). Because the rating scale used in this study was dichotomous, intra-observer agreement was not considered.

Within the limits of this ex vivo study, we conclude that the differences between LCD and CRT monitors for the evaluation of root canal fillings are clinically insignificant independent on whether conventional radiographs, captured by means of image plates, or cone beam images are being displayed.

Conflict of interest The authors declare that they have no conflict of interest.

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