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Efficacy of several digital radiographic imaging systems for laboratory determination of endodontic file length

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Abstract

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Aim To compare the efficacy of different digital radiographic imaging systems for determining the length of endodontic files.

Methodology K-type endodontic files were introduced into the canals of 40 extracted human permanent single-rooted teeth and fixed in place at random lengths. The teeth were radiographed using Digora Optime®, CygnusRay MPS® and CDR Wireless® digital imaging systems. Six observers measured every file length in all the images and repeated this procedure in 50% of the image samples, and assigned a score to the level of difficulty found. Analysis of variance for differences between digital systems and Tukey's test were performed. The level of intraobserver agreement was measured by intraclass correlation. The assigned scores were evaluated by Kruskal–Wallis and Dunn's tests.

Results The CDR Wireless values did not differ significantly from the actual lengths and the CygnusRay MPS values. The Digora Optime system was significantly different from the others and overestimated the values ($P \leq 0.05$). The Digora Optime was significantly easier to use for taking measurements and the CygnusRay MPS the most difficult ($P \leq 0.05$). All digital radiographic imaging systems showed excellent agreement with the Intraclass Correlation Coefficient >0.95.

Conclusions The three digital radiographic imaging systems were precise. The CDR Wireless system was significantly more accurate in determining endodontic file lengths, and similarly to Digora Optime, was considered the least difficult to use when assessing endodontic file lengths.

Keywords: digital dental radiography, endodontics, odontometry, software.

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Introduction

The study and development of digital radiographic imaging systems have contributed to this technology being increasingly accepted by dentists, since it has good image quality and is more convenient than film with several advantages in clinical practice (Parks & Williamson 2002, Woolhiser *et al.* 2005, Nair & Nair 2007, Hadley *et al.* 2008, Benchimol *et al.* 2009, Gormez & Yilmaz 2009). The main difference in digital imaging systems is the image receptor technology. Current systems use the following intraoral image receptor technologies: charge-coupled device (CCD) and complementary metal oxide semiconductor (CMOS) or photostimulable phosphor plates (PSP) (Ludlow & Mol 2004, Kamburoğlu *et al.* 2008).

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CMOS technology is the basis of typical consumer-grade video cameras. These detectors are silicon-based semiconductors but are fundamentally different from CCDs in the way that pixel charges are read (Ludlow & Mol 2004). Both systems present a direct and instant image that can be viewed on the screen immediately after radiographic exposure (Goodarzi Pour *et al.* 2008). This advantage makes endodontists prefer these sensors, although the active surface is smaller and they are connected to cables and wires. The introduction of wireless sensors in 2004 was welcome. The quality of an image produced by a solid-state detector (CCD or CMOS) is dependent not only upon the chip pixel dimensions, but also upon the type and configuration of the scintillator layer, the electronics including analog to digital conversion, and the acquisition and display software (Farman & Farman 2005).

The PSPs absorb and store energy from the X-ray and then release this energy as light (phosphorescence) when stimulated by other light of an appropriate wavelength (Schaefer-Prokop & Prokop 1997, Ludlow & Mol 2004). The quality of the image depends on the quality of the phosphor plate, scanning mechanism, electronics, and the acquisition and display software (Kamburoğlu *et al.* 2008).

Whilst endodontic files and working length can be estimated using several methods, radiographic verification is an important aid in root canal treatment (Versteeg *et al.* 1997, Woolhiser *et al.* 2005, Kazzi *et al.* 2007). Despite the introduction of accurate electronic apex locators (Pascon *et al.* 2009a,b), the usual method to determine the working length is a combination of knowledge of root lengths, tactile discrimination, assessment of a preoperative radiograph and a radiograph taken with files placed in the root canal (Nguyen *et al.* 1996, Versteeg *et al.* 1997). In an endeavour to provide more relevant diagnostic information, several image-processing algorithms have been designed. Digital measurement would allow greater precision, minimize the differences that occur in the subjective evaluation of radiographic images, provide important assistance to establish the accurate working length, and therefore, allow successful endodontic treatment (Kal *et al.* 2007).

Considering that digital radiographic imaging systems have been improved and updated, it is important to assess their performance through a comparative approach. Therefore, the aim of this laboratory study was to compare the efficacy of three digital radiographic imaging systems in determining the length of endodontic files.

Materials and methods

After local Institutional Research Ethics Committee approval (number: 069/2008), 40 extracted human permanent single-rooted teeth with intact surface and root canal free of calcification were used. One investigator performed all the technical procedures. Standard access cavities were accomplished using a water-cooled diamond fissure bur in a high-speed hand piece. The pulp chamber was cleaned of soft tissue with a dental excavator and the canal orifice was identified. Gates-Glidden drills nos. 2 and 3 (Dentsply Maillefer, Ballaigues, Switzerland) were used to enlarge the coronal part of the root canals. The teeth were prearranged into groups of four and an identification number was assigned to each tooth. Images on film were first conducted to measure the radiographic tooth length according to the paralleling technique, using the InSight® dental film (Eastman Kodak Co., Rochester, NY, USA), in an increasing numerical order. Automatic film processing, set at six minutes, was performed in a darkroom using the Gendex GXP® unit (Gendex Dental Systems, Lake Zurich, IL, USA). The distances between incisal border and apical limit were measured using an endodontic ruler (Dentsply Maillefer). In order to simulate the clinical situation the roots of the teeth were covered by a thin layer of wax and inserted into stone plaster mixed with powdered rice in the same proportion by volume.

Based on Ingle's radiographic method (Shanmugaraj *et al.* 2007) and the predetermined radiographic tooth lengths, size 10 and 15 K-type files (Dentsply Maillefer) were placed at random lengths ranging 0–2 mm from the apical limit. The actual file lengths were obtained with a ruler, and they were not related to tooth lengths to avoid possible negative interferences at a later stage. All data were recorded on a Microsoft Excel 2007 spreadsheet.

The teeth were then placed on an apparatus with the central X-ray beam directed through the interproximal area. The vertical angle was at a precise right angle to the centre of the image receptor and a rim provided reproducible exposure geometry. The source-object distance was fixed at 32 cm. An acrylic plate (24 mm thick) was placed between the X-ray tube and the teeth to simulate soft tissue scatter.

All teeth were radiographed with three digital radiographic imaging systems: PSP—Digora Optime® (Soredex, Helsinki, Finland), CMOS—CDR Wireless® (Schick Technologies Inc., Long Island City, NY, USA) and CCD—CygnusRay MPS® (Cygnus Technologies,

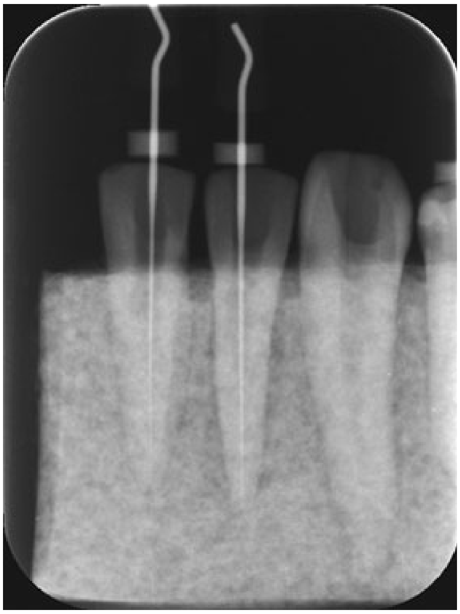

Figure 1 The resulting digital image.

Scottsdale, AZ, USA), with the GE 1000® dental X-ray unit (General Electric Company, Milwaukee, WI, USA) operating at 70 kVp and 10 mA for 0.2 s. The resulting images were stored as 8-bit TIFF files (Fig. 1).

Under subdued room lighting, six observers, including three radiologists and three endodontists with over 2 years of clinical experience, were asked to measure the distance (length) of every file from the rubber stop to the apical-most tip of the file. The digital images were displayed on a 15-in. LCD monitor and the measurements were performed using the distance measurement tool provided by the corresponding software imaging systems. Observers were not familiar with any of the software applications and they were allowed to adjust contrast and brightness. An interval of 1 week elapsed between use of each system.

Fifteen days later, in order to test intraobserver reproducibility, the observers repeated the measurements on a random selection of 50% of the image samples. To obtain a subjective analysis of the systems, they also assigned a score to the level of difficulty found in locating the tip of the file, according to a 5-category rating scale: [0] very hard; [1] hard; [2] undefined; [3] easy; [4] very easy. Analysis of variance (ANOVA) for differences between digital radiographic imaging systems and Tukey's test were performed. The level of intraobserver agreement was measured by Intraclass Correlation. The assigned scores were evaluated by Kruskal–Wallis and Dunn's tests. The significance level was set at 0.05.

Table 1 Mean values of file lengths (in millimetres ± standard deviation) from the rubber stop to the tip in the imaging systems and the actual lengths

Imaging system	Mean (mm)	SD
Actual lengths	22.05 b	2.10
CygnusRay MPS	21.62 c	2.37
CDR Wireless	21.82 bc	2.06
Digora Optime	22.64 a	2.14

Mean values followed by different letters differ by Tukey's test ($P \leq 0.05$).

Results

The CDR Wireless values did not differ significantly from the actual lengths and CygnusRay MPS values. CDR Wireless and CygnusRay MPS systems underestimated the actual lengths, whilst the Digora Optime system overestimated them (Table 1).

Subjectively, the level of difficulty of CygnusRay MPS and Digora Optime imaging systems were significantly different, but both did not differ from the CDR Wireless system which, on a rating scale, was considered as being of medium difficulty. The Digora Optime system was considered the easiest system to locate the tip of the file and CygnusRay MPS the most difficult (Table 2).

Intraobserver evaluation showed excellent agreement for all digital imaging systems, with means of intraclass correlation coefficient higher than 0.95 (Table 3).

Discussion

The morphology of the root apex varies not only as regards the position of the apical constriction, but also the location of the foramen (Williams *et al.* 2006, Herrera *et al.* 2007), which contradicts the theory of instrumentation up to 1 mm short of the root apex (Shanmugaraj *et al.* 2007, Siu *et al.* 2009). In this study, endodontic files were fixed in place spanning a range from the apical limit (zero) up to 2 mm short of it and radiographed with three different types of digital image receptors – PSP, CCD and CMOS. Studies have previously been performed to determine endodontic file lengths in root canals (Versteeg *et al.* 1997, Eikenberg & Vandre 2000, Hoer & Attin 2004, Pascon *et al.* 2009a,b). This is not the exact procedure performed during clinical endodontic treatment, but it allows the efficacy of the digital imaging system to be assessed with regard to reproducing real measures of the

Table 2 Absolute frequency and percentage of scores assigned, and medians to the level of difficulty found in locating the tip of the file by the observers

Imaging system	0 Very hard	1 Hard	2 Undefined	3 Easy	4 Very easy	Median Score
	Frequency (%)					
CygnusRay MPS	1 (16.7%)	3 (50.0%)	2 (33.3%)	0 (0.0%)	0 (0.0%)	1 b
CDR Wireless	0 (0.0%)	3 (50.0%)	0 (0.0%)	3 (50.0%)	0 (0.0%)	2 ab
Digora Optime	0 (0.0%)	0 (0.0%)	1 (16.7%)	3 (50.0%)	2 (33.3%)	3 a

Median values followed by different letters differ by Dunn's test ($P \leq 0.05$).

Table 3 Intraclass correlation coefficient means and minimum–maximum values

Imaging system	Mean	Minimum	Maximum
CygnusRay MPS®	0.968	0.945	0.989
CDR Wireless®	0.983	0.969	0.997
Digora Optime®	0.952	0.808	0.997

instrument and to check whether the observers determine its tip correctly.

Discrimination of file tips in a radiographic image may also be influenced by a number of factors including type of image receptor, effects of scattered radiation, superimposition of trabecular bone pattern, bone processes and roots, differences in bone density, and selection of the optimal exposure time (Friedlander *et al.* 2002). The exposure time, set at 0.2 s for all systems, was established based on the CCD system since it has the narrowest dynamic range and may compromise the image quality at overexposure (Wenzel & Møystad 2010). It has been suggested that size 10 endodontic files, or less, are not adequate for determining the working length because the files are indistinct and it is not usually visible on radiographs (Couture 2003). However, curved, fine, or partially calcified canals will often not allow passive placement of instruments up to the canal foramina. Instrumentation to enlarge the canal to a minimum of size 15 before determining the working length may result in transportation and deviation of the canal (Friedlander *et al.* 2002). In this study, K-type endodontic files sizes 10 and 15 were used at random working lengths in straight canals. Although it results in unsatisfactory radiographic visualization, file size 10 was assessed because it is widely used by dentists claiming that such size is needed for teeth with narrow canals. (Fuge *et al.* 1998, Friedlander *et al.* 2002).

Precision and accuracy are limited to the reliability and reproducibility of the area radiographed and the ability of the operator to determine the exact measurement (Körner *et al.* 2007). The excellent intraobserver reproducibility obtained in this study revealed that all observers were reliable as regards determining the endodontic files and all digital radiographic imaging systems allowed excellent precision. In the subjective analysis, Digora Optime was considered the best system to locate the tip of the file, since it allowed for better image quality. However, with the Digora Optime system, the minimum and maximum values of intraobserver reproducibility showed greater differences, which may be due to measurement procedures. Whilst the other two systems require only one click on the points of interest, in the Digora Optime software the measurement is only concluded after a double click. If the second click is not on exactly the same point, the final measurement may not be accurate and precise. The overestimation by the Digora Optime system may be due to the captured images having a larger pixel size (64 μm), when compared with the CDR Wireless (40 μm) and the CygnusRay MPS (20 μm) systems, because it is known that the pixel size describes the detail of an image and it varies inversely with the resolution (Couture 2003).

Conclusion

The three digital radiographic imaging systems allowed excellent precision, the CDR Wireless system was more accurate in determining endodontic file lengths, and similarly to Digora Optime, was considered the least difficult to use when assessing endodontic file lengths.

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