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ORIGINAL ARTICLE

In vitro comparison of three different image receptors for determining the length of endodontic files

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Abstract *Background/purpose:* The aim of this study was to evaluate the accuracy of endodontic file length measurements of E-speed radiographs, Digora storage phosphor plates, and Schick charge-coupled device sensors, with a secondary aim of assessing the influence of image enhancement on the measurement accuracy.
Materials and methods: Forty-seven extracted mandibular first premolar teeth were selected. ISO size 8, 10, and 15 files were inserted into each canal, and the files were fixed when the tip was seen at the apical foramen. The teeth were mounted in acrylic blocks and exposed using E-speed films, Digora storage phosphor plates, and Schick charge-coupled device sensors. Two radiologists and two endodontists measured the length of each file between the file stopper and tip on each image. Measurements were carried out on original and magnified images as well as on revealer images for Schick CDR. The actual lengths of the files were measured using a calipers to the nearest 0.01 mm and served as the "true length". Repeated measures analysis of difference and Tukey honestly significant difference tests were used to analyze the data ($P < 0.05$).
Results: E-speed films were superior to digital systems for the measurement accuracy of the size 08 file ($P < 0.05$). Revealer images gave equivalent results with E-speed films for the measurement of the size 10 file ($P > 0.05$). The most accurate results were obtained with the size 15 file regardless of the image receptor ($P > 0.05$).
Conclusion: Size 15 or larger files should be used for endodontic working length determinations. Revealer images gave equivalent results with E-speed films and may be utilized for determining the file length of size 10 files.

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Introduction

With the introduction of digital radiography, intraoral digital sensors became of particular interest in endodontics, where exposure of the patient to radiation and the time between exposure and image interpretation are of special importance.[1,2] Since then, digital radiography systems have been evaluated with regard to various endodontic tasks including working length estimation, the detection of periapical lesions, and the imaging of root canal anatomy.[1–3] Most of these studies have focused on comparing different imaging systems for visualizing the endodontic file tips, and it has been suggested that endodontic files smaller than ISO size 15 are not suitable for working length determination as the tips may not be clearly visible on a digital image.[4,5] As for the influence of image-processing algorithms on the visibility of endodontic file tips, contradictory results have been reported. Some authors have stated that digital image processing may improve the visibility of endodontic file tips,[6,7] while others have reported that difficulties exist when locating the tip of thin files such as ISO sizes 06 and 08 even with image-processing algorithms.[1,6–8]

The major limitation of these studies is that image quality assessments have often based on subjective evaluations that are difficult to quantify. In general, observers were asked to determine the position of the file tips as being shorter than or beyond the apex. However, it has been stated that it may be more important to use a computable objective measure rather than subjective assessments to predict diagnostic accuracy.[6,9] This is particularly important in endodontics as an accurately determined working length influences final verification of the outcome of root canal treatment. Therefore, it may be considered that, when comparing different imaging systems for the accuracy of endodontic file length measurement, it is more important to determine the actual length of the file rather than knowing that it is just, for instance, "shorter" than the apex.

The outcome of an endodontic treatment is a multifactorial event, and although it is not the sole determinant of the outcome, an accurate working length is an important consideration in endodontic procedures as it may lead to possible successful root canal treatment.[10] While the estimation of the endodontic working length can be achieved by various methods, mainly using electronic apex locators, radiographic verification is still an important aid in root canal treatment.[11] Consequently, the ability of radiographic images to provide the information required to accurately determine the length of endodontic files is of great importance.[12]

In studies comparing different imaging systems for the accuracy of endodontic file length measurements, digital images have mostly been acquired by charge-coupled device (CCD) sensors, with a few studies involving the use of Digora storage phosphor plate (SPP) images.[12–15] The influence of image-processing algorithms on the measurement accuracy of endodontic files has rarely been evaluated.[6,8]

Therefore, the primary aim of this study was to evaluate the accuracy of endodontic file length measurements using E-speed radiographs, Digora SPPs, and Schick CCD sensors, with the secondary aim of assessing the influence of magnification and an image-processing algorithm (Revealer) on the measurement accuracy, using a clinical simulation model.

Materials and methods

A total of 47 extracted permanent premolar teeth with single root canals were used for the study. The teeth were kept in 37% aqueous formaldehyde solution with 10% methanol. One investigator (IA) performed the technical procedures for all teeth. Access cavities were prepared using a water-cooled diamond fissure bur in a high-speed hand piece. Gates-Glidden drills (Dentsply Maillefer, Ballaigues, Switzerland) sizes 2 and 3 were used to enlarge the coronal part of the root canals. Size 08, 10, and 15 Hedstrom files (Dentsply Maillefer, Ballaigues, Switzerland) were inserted into each canal until the tip of the file was seen just at the root apex, and were fixed using a silicone stopper and composite resin material. Before exposure, each tooth was mounted in an acrylic block to represent the surrounding hard tissue and 15 mm thick Plexiglass was inserted between the X-ray tube and the teeth to simulate the effect of soft tissue during all exposures.[12]

Each sample was placed on a supporting post with the X-ray cone (Pentamix; 3M ESPE, St. Paul, MN, USA) to allow an exactly parallel alignment. In order to keep the receptors perpendicular to the beam at all exposures and to provide consistent and reproducible parallel imaging of the samples, a Rinn-Endo-ray film holder (Dentsply/Rinn Corporation, Elgin, IL, USA) was used to fix the X-ray tube. The Digora SPPs (Soredex Orion Corporation, Helsinki, Finland) were positioned in the same way with E-speed films (Eastman Kodak, Rochester, NY, USA), while the CCD sensors (Schick Technologies Inc, Long Island City, NY, USA) were immobilized with elastic bands. The standard geometric configuration was fixed at a 30 cm source to object distance, a 1 cm object to receptor distance, and zero degrees vertical and horizontal angulations of the X-ray beam. Radiographic images for each experimental tooth were obtained with E-speed film, SPPs, and CCD sensors with the X-ray unit operating at 65 kVp and 10 mA using the optimal exposure time recommended for each system (Trophy Radiologie, Vincennes, France). The exposure times were 0.25 seconds for the E-speed films and 0.16 seconds for the SPP and CCD sensors.

Conventional films were developed in an automatic processor (XR 24; Dürr, Bietigheim, Germany) with fresh solutions (Hacettepe, Ankara, Turkey) for 4 minutes and 30 seconds. The processed radiographs were mounted in transparent frames and placed on a viewbox. SPPs were scanned in the Digora FMX scanner previously calibrated for a highest exposure of 0.4 seconds and analyzed with the Digora for Windows software program (Soredex Orion Corporation), while Schick CDR Software (Schick Technologies Inc, Computed Dental Radiography for Microsoft Windows Version 2.6 Network) was used to analyze the CCD images.

Two radiologists and two endodontists with a mean age of 37.5 years (range 28–52 years) and a mean clinical experience of 14.2 years (range 6–26 years) acted as evaluators and were asked to measure the length of each file between the stopper and the tip of the file on each image. The viewing sessions were performed in a darkened room to minimize the glare. Film measurements were performed directly on the viewbox using a ruler to the nearest 0.5 mm. Measurements were made on both original and magnified images (×6) for conventional films. Digital images were displayed on a Philips Lightframe 107 P4 17-inch flat monitor (Philips Electronics, Koninklijke, Netherlands) as TIFF files, and the measurements were performed using the distance measurement tool provided by the software. The measurements were made on both the original and magnified images for SPP and CCD images with the zoom tool applied once for a magnification of 100%. Additionally, the measurements were performed on Revealer images for Schick CDR (Fig. 1). Image sequencing was same for all observers.

Thereafter, the file in each canal was removed and the distance from the file stopper to the tip was measured three times using a digital caliper (Akyol Commercial Company, Istanbul, Turkey) to the nearest 0.01 mm, with the mean was recorded as the "true length". A mean (from all four observers) was calculated for measurements obtained from each image and file size. In order to simplify the statistical analysis, the mean error in each reading was calculated as the absolute value of the difference between an observer's measurement and the true length in case negative or positive values would cancel each other out. The mean absolute errors were then compared for all observers for each imaging modality and each file size using repeated-measures analysis of variance (ANOVA). Pairwise comparisons were performed with the Tukey honestly significant difference test. The level

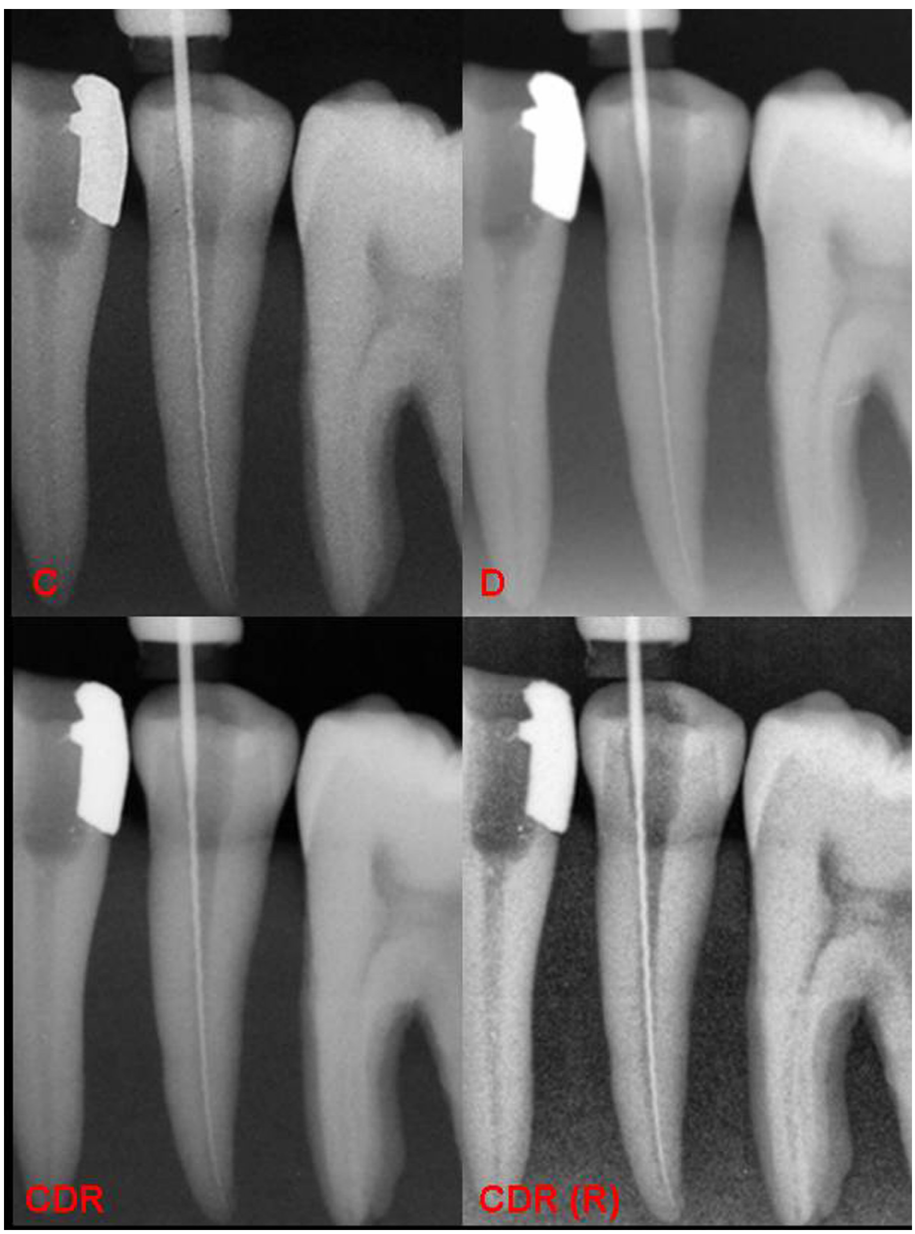

Figure 1 Conventional and digital radiographic images of a size 15 file. C = Conventional film; D = Digora SPP; CDR = Schick CDR; CDR (R) = CDR Revealer.

of statistical significance was set at 0.05 for all analyses (SPSS 13.0 for Windows; SPSS Inc., Chicago, IL, USA).

Results

Repeated measures ANOVA showed significant differences among the different imaging modalities and three file sizes ($P < 0.05$), but not among the observers ($P > 0.05$). The results presented in Table 1 demonstrate the mean absolute error values of three endodontic files measured using different imaging modalities.

The measurements from the original and magnified E-speed films presented significantly lower mean error values than the digital imaging modalities for the size 08 file ($P < 0.05$). This means that conventional film provided a file length that was quite similar to the true length of the size 08 file. As for the digital modalities, the Revealer images presented the lowest mean error value for the measurement of size 08 file, with the difference between Revealer and magnified SPPs images being statistically significant ($P < 0.05$). For the size 10 file, original E-speed films, Revealer images, and magnified E-speed films respectively gave significantly lower mean error values than other imaging modalities ($P < 0.05$). The lowest mean error values were obtained for the size 15 file regardless of the imaging system used ($P > 0.05$).

The influence of magnification on measurement accuracy was not significant for the conventional and digital imaging modalities or for the three different files sizes in this study ($P > 0.05$).

When the accuracy of the measurements for each image receptor was compared with respect to the file size, a statistically significant decrease in mean error value was observed with increasing file size for all imaging modalities used in this study ($P < 0.05$). In other words, the accuracy of measurements increased with increasing file size.

Discussion

In most of the studies comparing different imaging systems in terms of the visibility of endodontic file tips, it was reported that the visibility of file sizes 20 and greater is comparable for all techniques, and that the file thickness should be as large as possible.[4,16] Some studies have reported an improvement in the discrimination of small file tips with the use of image-processing algorithms such as magnification and negative to positive conversion.[14,17] However, it must also be remembered that it may be more difficult to visualize small file tips in clinical situations owing to problems of the selection of optimal exposure time, the effects of scatter radiation, and differences in bone density. It has been suggested that files made of a high-density metal alloy are used in order to utilize size 08 and 10 files for endodontic length determination when a digital imaging system is being used.[14,17] Similarly, in studies evaluating different imaging systems in terms of the accuracy of endodontic file length measurements, it has been stated that digital radiography does not afford sufficient diagnostic accuracy for file sizes 10 or smaller. Nevertheless, these techniques have been found to be of equal performance to conventional film for file sizes 15 or larger.[18] In a few studies comparing the accuracy of file length measurements from CCD and SPP images, no statistically significant differences were observed between these two systems, and the agreement was best with size 15 files.[8,19]

In accordance with the above-mentioned studies, our results also indicate that Digora SPPs and CCD sensor images are comparable to conventional film in terms of accuracy of endodontic file length measurement of size 15 files. However, both systems were inferior to conventional film for accurately measuring size 08 and 10 files. The only exception occurred with the use of a particular image-processing algorithm for CCD images, which presented measurements that were equivalent to conventional film measurements for the size 10 file.

When comparing the performances of different imaging systems, the density of the test object and the radiation source have to be constant since they will determine the image clarity and the amount of detail on the radiograph. The geometric requirements must also be optimized by placing the film and object in parallel and ensuring precise angulations of the X-ray beam.[20] Furthermore, the brightness and contrast of the digital images should be fixed to allow an equal chance of comparable performance for those observers less experienced with digital images. By providing a constant and reproducible relationship between image receptors and test objects, and using fixed settings

Table 1 The mean error ± standard deviation values of endodontic files for different imaging modalities.

	Size 08 file (mm)	Size 10 file (mm)	Size 15 file (mm)
E-speed	0.320 ± 0.220[a]	0.010 ± 0.040[c]	0.006 ± 0.030
E-speed ×6	0.300 ± 0.200[a]	0.010 ± 0.040[c]	0.006 ± 0.030
CDR original	1.020 ± 0.580	0.150 ± 0.150	0.020 ± 0.070
CDR ×100	1.140 ± 0.700	0.150 ± 0.140	0.010 ± 0.060
CDR Revealer	0.840 ± 0.510[b]	0.010 ± 0.040[c]	0.006 ± 0.020
SPP original	1.280 ± 0.610	0.190 ± 0.120	0.020 ± 0.050
SPP ×100	1.440 ± 0.820[b]	0.170 ± 0.150	0.025 ± 0.053

SPP = storage phosphor plate.
[a] E-speed and magnified E-speed images presented significantly lower mean error values than digital imaging modalities ($P < 0.05$).
[b] CDR Revealer images presented significantly lower mean error value than SPP magnified images ($P < 0.05$).
[c] E-speed, magnified E-speed, and CDR Revealer images presented significantly lower mean error values than other imaging modalities ($P < 0.05$).

during viewing sessions, we may consider that image receptor characteristics are responsible for the differences in accuracy of endodontic file length measurements between imaging systems.

Radiographic systems are often compared using the line pair per millimeter test tool, which gives a measurement of resolution. The spatial resolutions of conventional films have been shown to be greater than 20 line pairs (mm^{-1}).[21] The pixel size of Digora and Schick CDR as given by the manufacturer are 0.071 mm (71 μm × 71 μm) and 0.04 mm (40 μm × 40 μm), respectively. Although the resolution performances of digital imaging systems are inferior to those of conventional film, they are likely to be adequate for most clinical tasks encountered in dental radiography. Initial experiments in this area suggest that the use of a 100 μm pixel size is acceptable for dental diagnostic purposes.[22] However, since the smallest detectable detail on an image is mainly a function of the spatial resolution, higher resolution values could well be needed to accurately measure the lengths of fine endodontic instruments.[23]

The Nyquist frequency is defined as the highest frequency that can be coded at a given sampling rate in order to be able to fully reconstruct the signal. According to this theorem, the spatial resolution of the system must equal twice the spatial frequency of the smallest detail in order to be detected.[6,23] Therefore, it may be easy to calculate that the minimum size of the detectable detail with Digora SPP and Schick CDR images would be 0.14 mm and 0.08 mm, respectively. The tip dimensions of size 8, 10, and 15 (Hedstrom) files were measured as 0.077 mm, 0.099 mm, and 0.147 mm in a recent study, which may explain the difficulties in locating the tip of the smallest file for both Digora SPP and Schick CDR images.[24] As can be expected, detectability of the file tip and consequently the accuracy of length measurement increase as files become thicker and cover more pixels of the digital images. However, it should be emphasized that our results might have been different with the use of other endodontic instruments such as K-files. It is well known that the tip dimension of these files is slightly larger than that of Hedstrom files, and it would have been reasonable to use these or larger instruments to optimize the visibility.[24] Although, it has been reported that fine instruments are better for testing different imaging systems, it is also proven that smaller files may be incompletely seen on digital images.[1,20,25] Since the evidence suggests that large files present no challenge to any imaging system, the present authors also included size 08 and 10 files to allow for a determination of absolute accuracy of the systems for endodontic file length measurement.

Comparing our results with the two previous studies in which the accuracy of endodontic file length measurements from CCD and SPP images were evaluated, we also observed that the original CCD and SPP images presented similar measurements for the size 15 file.[8,19] Statistically significant differences were observed between these two systems with the use of image-processing algorithms for size 08 and 10 files, and CCD images provided more accurate measurements than SPP images. Although the image quality of CCD systems has been shown to be superior to that of SPP systems, the Digora system was shown to have better low-contrast detectability than the CCD sensors, which favors it when imaging low-contrast structures such as empty root canals.[2,22,26] The impairment of low-contrast detectability for Digora with endodontic files inserted in the root canal space and the higher spatial resolution for the Schick CDR may account for the differences between the endodontic measurement accuracy of these systems. However, as can be seen in Table 1, these differences can be regarded as divergences that are clinically insignificant, and it may be concluded that the Schick CDR and Digora SPP systems have comparable performances when utilized for endodontic file length measurement.

It has been reported that image-processing methods accentuate or emphasize particular objects or structures in an image by manipulating different features.[27] However, it has also been stated that improperly used enhancements may decrease diagnostic performance, and the selection of a proper procedure is time-consuming since the clinicians are required to browse through potential enhancement techniques subjectively.[28] Therefore, when a new image-processing algorithm is introduced, the first question that needs to be answered is whether or not the algorithm is beneficial and improves diagnostic accuracy regarding a specific clinical task, compared with previously established methods. The Revealer image-processing algorithm is based on pixel-by-pixel enhancement attempting to improve the diagnostic quality of digital radiographic images (Schick Technologies Inc). No significant differences were reported among conventional films and Revealer images for the measurement accuracy of size 15 files.[12] Our results indicate that enhancing the pixel values using the Revealer has slightly improved the measurement accuracy of endodontic files, and no significant difference was observed between conventional film and Revealer images for the measurement accuracy of the size 10 file. Therefore, this image-processing algorithm may be recommended when utilizing CDR images endodontic file length determinations of size 10 files.

As for the magnification, it was stated that zooming in with an image does not necessarily improve diagnostic performance, and there is an upper limit at which diagnostic accuracy may be reduced.[29] This may be due to the difficulty of locating the apices and the tip of the file in a magnified image. In accordance with the previous reports, no significant influence of magnification on the measurement accuracy of endodontic files was observed in the present study.[8,29]

The most accurate endodontic file length measurements were obtained with the size 15 file for each of the imaging systems. Therefore, endodontic files smaller than size 15 should not be used for working length determinations in clinical situations. However, the enhanced CDR images presented equivalent measurements to E-speed films, and this new image-processing algorithm may be utilized for length determination of size 10 files. The magnification of conventional films and digital images does not improve the accuracy of endodontic file length measurements.

Conflicts of interest

The authors declare that there are no conflicts of interest that could influence their work.

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