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High resolution charge-coupled device sensor vs. medium resolution photostimulable phosphor plate digital receptors for detection of root fractures *in vitro*

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Abstract – The aim of this study was to compare the diagnostic accuracy of a high resolution charge-coupled device (CCD) sensor and a medium resolution photostimulable phosphor (PSP) plate for detecting experimentally induced root fractures and further, to evaluate differences between images taken with various horizontal and vertical angles. Forty-seven extracted single-rooted human teeth mounted in a dry human skull were used in the experiment. The teeth were radiographed, before and after root fractures were induced, with two digital receptors: the Digora® PSP system (approx. 8 lp mm^{-1}) and the RVG-ui™, a CCD sensor with a high-resolution mode (15–20 lp mm^{-1}). Four images were taken with each of the receptors of each tooth: one orthogonal exposure (O-images), one exposure with a vertical angle of 15° by which the root was imaged elongated (L-images), and two eccentric exposures with a horizontal angle of 15° mesially and distally. Three observers marked a fracture line if detected, in each image. Three sessions were held, one assessing the O-images, one the L-images, and one in which all four images of the same tooth were displayed simultaneously (X-images). The RVG-ui™ images obtained higher sensitivities than the Digora® PSP images ($P < 0.05$). Sensitivity was statistically significantly higher for the X-images than for both the O-images and the L-images ($P < 0.05$). Based on the observed means, specificities were significantly different neither between the angles, nor between the images from the two digital systems taken with the same angle ($P > 0.05$). It may be speculated that the difference in spatial resolution between the two digital systems accounts for the differences in their sensitivity.

Key words: digital; radiography; dental; root fracture; traumatology; tooth

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The validity of recent digital radiography systems has been reported for various diagnostic tasks, such as caries detection, periodontal disease, periapical pathology, endodontics, implant research, root resorption and cephalometry (for review: 1). In the vast majority of these diagnostic studies, the digital systems have been found to be as accurate as current dental films for the detection of dental pathology. The digital receptors in their first versions (6–8 lp mm^{-1}) did not match the spatial resolution provided by the dental film, but more recent developments, particularly of some charge-coupled device (CCD)-based sensors, are characterized by providing a spatial resolution reaching that of film (2, 3).

For some diagnostic tasks, e.g. detection of the position of small root files in endodontic treatment, some digital receptors have been found to be inferior to film (4–6). In a recent study (7) the error when detecting file length was significantly smaller for a high-resolution digital receptor (RVG-4, Trophy) than for a storage phosphor plate system with lower resolution (Digora, Soredex) while in studies on accuracy of caries diagnosis, differences between these two systems could not be extracted (8, 9).

It may be speculated that for very elaborate diagnostic tasks, e.g. localization of the tip of the smallest root files, a higher spatial resolution may be demanded than has hitherto been available with most digital systems. Another example may be root fractures, which may be difficult to visualize in a radiograph, particularly immediately after the trauma if the two root fragments are not displaced. This diagnostic task may also demand a high spatial resolution of the receptor.

The aim of this study was to compare the diagnostic accuracy of a high-resolution CCD sensor and a photostimulable phosphor (PSP) plate for detecting experimentally induced root fractures and further, to evaluate differences between images taken with various horizontal and vertical angles. The hypothesis to be tested was that no significant difference exists between the radiographic receptors and projection angles for detection of horizontal root fractures.

Material and methods

Forty-eight extracted single-rooted human teeth were used in the experiment. The reason for extraction and age and sex of the individuals were unknown. The teeth were mounted in empty dental alveoli in a dry human skull, and a 20 mm acrylic bloc was used to simulate soft tissue scatter. The teeth were radiographed in the facio-lingual view with two digital receptors: the Digora® PSP system (approx. 8 lp mm^{-1}, Soredex/Orion Corp., Helsinki, Finland) and the RVG-ui™, a CCD sensor, which provides a high spatial resolution when used in the 'high-resolution mode' (15–20 lp mm^{-1}, Trophy Radiologie Inc., Paris, France). Four exposures were taken with each of the receptors of each tooth: one orthogonal exposure (O-images), one exposure with a vertical angle of 15°, by which the root was imaged elongated (L-images), and two eccentric exposures with a horizontal angle of 15° mesially and distally to the O-projection (Fig. 1). The phosphor plates were scanned in the system scanner (fmx scanner, Soredex/Orion, Corp., Helsinki, Finland).

Root fractures were induced in the horizontal plane by a mechanical force to the root (the use of a hammer with the tooth placed on a soft foundation). Ten teeth not included in the study were used to learn the force that was needed to break the root in two fragments. Nevertheless, eight teeth broke in more than two fragments, and these teeth were excluded from the study. In the remaining teeth, the two fragments were thoroughly held together and glued. To be able to clearly identify the fracture site, the fracture line was delineated on the root with a red pen after gluing. The radiographic examinations were thereafter repeated. All digital images were exported and displayed in a specially designed software program with the ability to adjust density, contrast, gamma curve, and magnification. The images with and without root fractures were coded and exposed to the observers in a random order.

Three observers assessed the images without knowing in how many of the images a root fracture was present. They could use the image enhancement facilities as they pleased. In the first session, the orthogonal (O-) images were assessed, in a second session, the elongated-root (L-) images and in a third session, all four images obtained with different angles of the same tooth (X-images) were displayed simultaneously. 17" monitors were used for the assessments. For each tooth the observers determined whether or not a root fracture was present. If they detected a root fracture, they indicated the fracture site by marking with the mouse where the fracture line crossed the root surface mesially and distally.

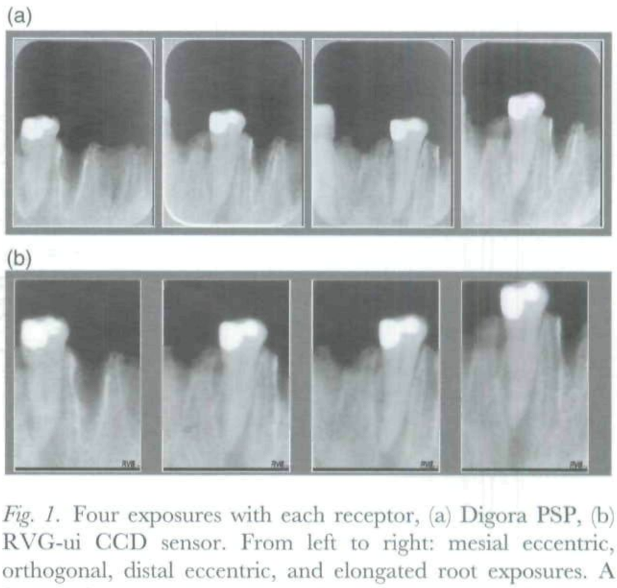

Fig. 1. Four exposures with each receptor, (a) Digora PSP, (b) RVG-ui CCD sensor. From left to right: mesial eccentric, orthogonal, distal eccentric, and elongated root exposures. A fracture is present, but not equally well detected in all images.

The person (L-LK), who had fractured the roots, also marked the true position of the fracture line on the images. Consulting the teeth with the fracture line drawn in red, she marked the correct fracture site in all radiographs separately. Moreover, she marked the cemento-enamel junction proximally and the most apical point of the root, which later served as reference points for calculating the site of the fracture (Fig. 2). This person did not serve as an observer for detecting the fractures. By calculating the *x,y*-coordinates in each image, it could be established whether a 'line' perceived and marked by the observers was in fact the fracture line.

Data treatment

Fracture/non-fracture assessments were categorized as follows: correct identification of a non-fractured root (true negative); correct identification of fracture site in a fractured root (true positive, a limit of 10% of the root length around the true fracture line was allowed for, to take manual dexterity into account); identification of a fracture in a non-fractured root (false positive); no identification of a fracture in a fractured root (false negative); and incorrect identification of the fracture site in a fractured root (counted as false negative). For the X-images, a correct line marked on any image represented a correct decision for the case (the theoretical situation with a mixture of correct and incorrect line markings on two or more of the X-images was never observed). Sensitivity and specificity rates were calculated for the O-, L- and X-images separately, with both digital systems. Overall differences in sensitivity and specificity between the digital modalities, the differently angled images and the observers were analyzed by 3-way analysis of variance with receptor type (two modalities), projection view (three angles) and observer (three observers) as the factors. Pair-wise comparison between receptors, projection views and observers were made by *post hoc t*-tests.

Fig. 2. The true fracture line marked in the orthogonal exposure of the RVG-ui image.

Results

Table 1 shows the sensitivities and specificities for the differently angled images with the two digital systems assessed by the three observers. Based on the observed means, the RVG-ui™ images obtained higher sensitivities than the Digora® PSP images ($P < 0.05$). Sensitivity was statistically significantly higher for the X-images than for both the O-images and the L-images ($P < 0.05$). Specificities were significantly different neither between the angles, nor between the images from the two digital systems taken with the same angle ($P > 0.05$). Observers 1 and 2 obtained significantly different accuracy rates ($P < 0.05$), while no significant differences were seen between the observers 1 and 3, or 2 and 3.

Discussion

Root fractures in the horizontal plane occur most frequently after acute trauma to the teeth. A single transverse fracture in the middle or apical third of the root is the usual finding (10). Radiography is the most commonly used method to aid in the diagnosis of such fractures. When interpreting the radiograph, one should look for a radiolucent line between the fragments and discontinuity of the periodontal ligament shadow (11). In this *in vitro* study, the fragments were tightly glued together in their original position and no attempt was made to displace the fragments. The situation may therefore resemble the immediate post-trauma clinical situation where no edema or granulation tissue has yet displaced the fragments.

A minimum of two radiographic views with different vertical angulations of the X-ray tube have

Table 1. Sensitivities and specificities for the sets of images (O-, L-, X-) containing different projection views obtained with two digital systems and assessed by three observers

	RVG™ sensitivity			Digora® sensitivity			RVG™ specificity			Digora® specificity		
	O	L	X	O	L	X	O	L	X	O	L	X
Observer 1	0.45	0.45	0.63	0.30	0.35	0.60	0.88	0.98	0.96	0.81	0.88	0.90
Observer 2	0.58	0.60	0.63	0.58	0.48	0.60	0.50	0.71	0.96	0.50	0.75	0.85
Observer 3	0.43	0.63	0.70	0.45	0.45	0.60	0.88	0.94	0.77	0.79	0.81	0.85
Mean	0.49	0.56	0.65	0.44	0.43	0.60	0.75	0.88	0.90	0.70	0.81	0.87

been recommended to increase the possibility that the X-ray beam is in alignment with the plane of the fracture line (10–12). Not many studies have looked into the additional effect of having access to various radiographic projections, although (13). In the present study, the 4-image view (X-images) included radiographs obtained with two vertical and three horizontal angles. The 4-image view was significantly more accurate than both the two vertical views separately while no differences existed between these. It may therefore be recommended that more than two views with various vertical and horizontal angles may be used in the diagnosis of root fractures. There were several weeks between the observers' assessment of the sets of differently angled images, and many of the teeth had very similar appearances. Memory bias because of the order of reading the images is therefore quite unlikely.

In the present study, a significant difference was observed between the two digital systems, i.e. the RVG-ui™ CCD sensor was more accurate than the Digora® storage phosphor plate for the 15° vertically angled images displaying the root elongated. Although not significantly different, the RVG-ui™ did in fact obtain higher sensitivities and specificities than the Digora® system for the other image angles as well by the majority of the observers. It may be speculated that the difference in spatial resolution between these systems accounts for the differences found.

A few previous *in vitro* studies have evaluated root fractures induced by a mechanical force to either endodontically treated or non-treated teeth by digital radiographic techniques. One study assessed the accuracy of the Sidexis CCD sensor compared with film for detection of such fractures (14) and found the sensitivity to be 86% and the specificity 84% for the digital system. This was not significantly different from film. Only one orthogonal image was available for each tooth. In that study, the teeth were radiographed without any bone simulation. This may explain the rather high sensitivities and specificities that were obtained. Other studies have evaluated the concept of Tuned Aperture Computed Tomography (3D viewing, TACT) compared with images obtained by the Schick CMOS (complementary metal oxide semiconductor) sensor (15, 16). In one study (15) detecting vertical fractures, nine images with different angles were available of each tooth. The sensitivity and specificity in the conventional 2D images taken by the sensor were low, on average 28% of the truly fractured roots were detected while only 33% of the non-fractured roots were classified as such. The 3D TACT images obtained higher sensitivity (55%) and specificity (82%). In another study (16), horizontal fracture lines in non-restored teeth were similarly detected more accurately with TACT than in the nine two-dimensional radiographs. In that study, the sensitivities were in line with those obtained in the present study while specificities were much lower. None of the above mentioned studies tried to reveal whether the line detected as a fracture line was in fact the true fracture line as the observers were not asked to mark the line they detected, and therefore the fraction of 'true positive' observations may be higher in these studies. These studies also did not evaluate whether some views were more accurate than others as all nine views were available at the same time for assessment. In the present study between 5 and 17% of the lines detected, depending on the observer and angle, were not the fracture line, and as such they were counted as false negative observations as the true fracture line was not detected. Our sensitivities had therefore been higher, had we counted the falsely assessed lines as a true positive outcome.

In conclusion, while significant differences between observers indicated that results would not be the same for all clinicians, The RVG-ui™ images provided significantly higher sensitivities for detection of a root fracture than did the Digora® PSP images. In addition, multiple projection views of the root, available simultaneously, provided significantly higher sensitivities than orthogonal or vertically angled views alone.

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References

1. Wenzel A. Matters to consider when implementing direct digital radiography in the dental office. Int J Comput Dent 1999;2:269–90.
2. Farman AG, Farman TT. RVG-ui: a sensor to rival direct exposure intra-oral x-ray film. Int J Comput Dent 1999;2:183–96.
3. Ludlow J, Mol A. Image-receptor performance: a comparison of Trophy RVG UI sensor and Kodak Ektaspeed Plus film. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2001;91:109–19.
4. Hedrick RT, Dove B, Peters DD, McDavid WD. Radiographic determination of canal length: direct digital radiography versus conventional radiography. J Endod 1994;7:320–6.
5. Sanderink GCH, Huiskens R, van der Stelt PF, Welander U, Stheeman E. Image quality of direct digital intraoral x-ray sensors in assessing root canal length. Oral Surg Oral Med Oral Pathol 1994;78:125–32.
6. Velders XL, Sanderink GCH, van der Stelt PF. Dose reduction of two digital sensor systems measuring file length. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996;81:607–12.
7. Vandre RH, Pajak JC, Abdel-Nabi H, Farman TT, Farman AG. Comparison of observer performance in determining the position of endodontic files with physical measures in the evaluation of dental x-ray imaging systems. Dentomaxillofac Radiol 2000;29:216–22.
8. Hintze H, Wenzel A. Influence of the validation method on diagnostic accuracy for caries. A comparison of six digital and two conventional radiographic systems. Dentomaxillofac Radiol 2002;31:44–9.
9. Hintze H, Wenzel A, Frydenberg M. Accuracy of caries detection with four storage phosphor systems and E-speed radiographs. Dentomaxillofac Radiol 2002;31:170–5.
10. Andreasen JO, Andreasen FM. Textbook and color atlas of traumatic injuries to the teeth. 3rd edn. Copenhagen: Munksgaard Mosby; 1994. pp. 281–4.
11. Whaites E. Essentials of dental radiography and radiology. 3rd edn. London: Churchill Livingstone; 2002. pp. 348–51.
12. White SC, Pharoah MJ. Oral radiology. Principles and interpretation. 4th edn. St. Louis: Mosby; 2000. pp. 571–3.
13. Degering CI. Radiography of dental fractures. An experimental evaluation. Oral Surg Oral Med Oral Pathol 1970;30:213–9.
14. Kositbowornchai S, Nuansakul R, Sikram S, Sinahawattana S, Saengmontri S. Root fracture detection: a comparison of direct digital radiography with conventional radiography. Dentomaxillofac Radiol 2001;30:106–9.
15. Nair MK, Nair UP, Gröndahl H-G, Webber RL, Wallace JA. Detection of artificially induced vertical radicular fractures using Tuned Aperture Computed Tomography. Eur J Oral Sci 2001;109:375–9.
16. Nair MK, Nair UP, Gröndahl H-G, Webber RL. Accuracy of tuned aperture computed tomography in the diagnosis of radicular fractures in non-restored maxillary anterior teeth. Dentomaxillofac Radiol 2002;31:299–304.