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The effects of digital image enhancement on the detection of vertical root fracture

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Abstract – *Aim*: To determine the effects of digital image enhancement on observer ability to detect experimentally induced vertical root fractures (VRF). *Material and methods*: A total of 64 extracted human mandibular premolar teeth were used in this study. In 32 teeth, VRFs were created in the bucco-lingual planes by gently tapping with screw-type root-canal pins. The remaining 32 intact teeth served as a control group. Digital images were obtained using a charge coupled device sensor. Three observers separately examined the original and four types of digitally enhanced images (enhanced using sharpness, zoom-in, reverse-contrast, and pseudo-3D functions) at 1-week intervals. All teeth were evaluated using a 5-point scale for the presence/absence of VRF. Evaluations of each image set were repeated 1 month after the initial viewings. Kappa coefficients were calculated to investigate the degree of intra- and inter-observer agreement. The areas under the receiver operating characteristic (ROC) curves (Az values) were calculated using the MedCalc statistical software. ROC values for each image type, observer and viewing were compared using *t*-tests. A level of $\alpha = 0.05$ was considered significant. *Results*: Kappa coefficients for intra-observer agreement ranged from 0.304 to 0.679. Inter-observer agreement kappa values ranged from 0.109 to 0.399 for the first reading and from 0.106 to 0.380 for the second reading. Statistical comparisons between Az values for each observer showed no significant differences ($P > 0.05$) among image types. *Conclusion*: There were no differences in diagnostic outcomes among differently enhanced images in the *in vitro* detection of VRF.

Vertical root fracture (VRF) can occur as a complication during or after root-canal treatment. The condition is difficult to diagnose and may require tooth extraction (1, 2). The major aetiological factors for VRF are root-canal treatment and excessive operative procedures performed in the root-canal (3). VRF may also lead to the development of bony lesions the radiographs of which show halos, perilateral radiolucency and angular resorption of the crestal bone (4, 5). Therefore, early detection of VRF can prevent extensive damage to supporting tissue. With VRF, the fracture runs lengthwise from the crown towards the apex and is usually oriented bucco-lingually. The fracture may appear as a radiolucent line on a radiographic image if the central ray of the X-ray beam is focused on the fracture plane (6).

Although intraoral periapical imaging does not provide three-dimensional information, it still provides the best spatial resolution of any imaging method currently available. Many dental practices have replaced traditional film with digital imaging systems because of lower levels of associated radiation exposure and faster imaging time, as well as improved patient education and associated perceptions regarding digital imaging (7). *Ex vivo* studies have found digital intraoral radiography to be comparable to film in the detection of VRF; however, these studies were not designed to assess the effects of individual enhancement tools (8, 9). Digital image technology offers a multitude of options for improving the visual quality of diagnostic images, with the most appropriate enhancement technique varying according to imaging modality, viewing conditions and the specific diagnostic task at hand (10, 11). Zooming in (magnification) function is claimed to be an accepted advantage of digital imaging. Pixels are duplicated (magnification 2:1, factor 2) or triplicated (magnification 3:1, factor 3) (12). Reverse-contrast is another electronic image processing tool which changes the radiographic positive image into a radiographic negative image (11). Pseudo-3D/embossing filter gives a 3D appearance to X-ray images. Some clinicians suggest use of reverse-contrast filter and pseudo 3D/embossing filter in detection of periodontal ligament width, early periapical lesion detection, alveolar crestal bone height and interproximal caries (13). Sharpening filter is used to improve image quality by removing blur or noise. Visibility of edges is increased selectively by using sharpening filter (10). The use of those filters result with subjectively visually more appealing radiographic images; however, there is no scientific evidence suggesting an increase in diagnostic value (10, 11, 13). Relatively few studies have specifically addressed the role of filters in image enhancement, and their usefulness is still a matter of debate (11).

The purpose of this study was to determine the effects of different image enhancement features on observer ability to detect experimentally induced vertical root fractures from digital images. The null hypothesis was that Az values obtained from original unenhanced images and four types of digitally enhanced images (enhanced using sharpness, zoom-in-magnification, reverse-contrast and pseudo-3D functions) would not differ.

Material and methods

The study material comprised 64 extracted human mandibular single rooted premolar teeth without root fractures that had not undergone any root-canal treatment. Extraction was performed for reasons including caries, periodontitis, alveolar bone loss, ectopic localization and orthodontic indication. Age, gender and the reason for extraction were not considered among the inclusion criteria. Teeth were placed in 1% hypochlorite solution over-night to remove soft tissues and calculus. Thereafter, they were stored in distilled water containing thymol. Afterwards, each tooth was immobilized by embedding in putty impression material. All root-canals were accessed coronally with a diamond bur, instrumented to a size 40–60 stainless steel K-file and irrigated with 2% sodium hypochlorite (NaOCl) following each change in instrumentation. Canals were filled with gutta-percha and endomethasone. The fillings were subsequently removed up to the apical two-thirds using a no. 6 Gates Glidden drill. In 32 of the teeth, VRFs were created in the bucco-lingual plane by gently tapping with a screw-type root-canal pin using controlled pressure by one researcher (prosthodontist) until a sharp 'cracking' voice was heard. The remaining 32 intact teeth served as controls. Teeth were randomly distributed into 16 groups of 4, numbered and placed in the empty mandibular premolar sockets of a dry human mandible.

Radiographic images of all teeth were exposed using an AET-Orix 70 (ARDET, Buccinasco, Italy) operated at 70 kVp and 8 mA and recorded using a 2-million pixel X-ray max charge coupled device (CCD) direct digital intraoral sensor size 2 (Benlioğlu Dental, Ankara, Turkey) (Sensor manufacturer: Dr. Suni, Suni Imaging, San Jose, CA, USA). Sensor was placed in putty material for fixed placement of the sensor in a standard position. For each tooth, orthoradial projections were taken bucco-lingually with a focus-receptor distance of 20 cm and an exposure time of 0.04 s, making a total of 64 images (Fig. 1). All images were captured and stored using the Dental Imaging Software, Version 1.0 (Benlioğlu Dental).

All images were evaluated separately by three calibrated observers (observer 1: oral radiologist; observer 2: general practitioner; observer 3: doctoral student) for the presence or absence of VRF. Observers were calibrated in a private session. They were shown some examples of images of teeth obtained from pilot studies. Also use of the imaging software was demonstrated and evaluation procedure described. Images were viewed in a dimly lit room on a 15' Toshiba Satellite monitor set at a screen resolution of 1024 × 768 pixels and 32-bit colour depth.

Image sets included the original unenhanced images and four types of digitally enhanced images (enhanced using sharpness, zoom-in-magnification, reverse-contrast and pseudo-3D functions) (Figs 2 and 3). We had a total of five image sets (unenhanced, enhanced using sharpness, zoom-in-magnification, reverse-contrast and pseudo-3D functions) each comprising 64 images of 64 teeth. Each image set was evaluated separately. Image sets were viewed at 1-week intervals and evaluations of each image set were repeated 1 month after the initial viewings. All teeth were evaluated randomly for the presence/absence of VRF and scored using a 5-point scale, as follows: 1 = fracture definitely present; 2 = fracture probably present; 3 = uncertain-unable to tell; 4 = fracture probably not present; and 5 = fracture definitely not present. Images were enhanced by one researcher for the desired filter for each session. One exception to this was zoom-in because it was not possible to change and save the magnified digital images in the software. As a result, observers had to zoom-in/magnify the images. The scores obtained from the observers were also recorded by the same researcher who knew the study design and enhanced the images. Observers were aware of the fact that some teeth were left without fractures.

Fig. 1. CCD sensor was placed in putty material for fixed placement of the sensor in a standard position for imaging of each specimen.

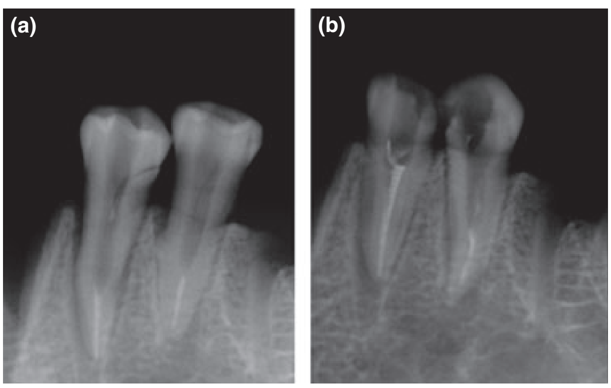

Fig. 2. Original images of premolar teeth obtained by the CCD sensor. (a) Teeth with VRF; (b) teeth without VRF.

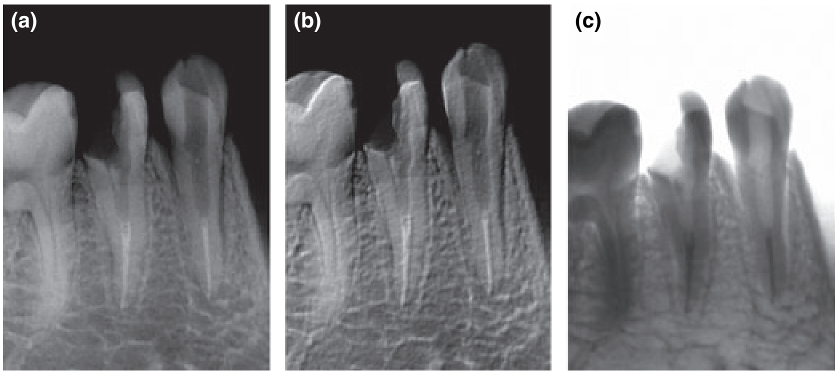

Fig. 3. Digital images enhanced after processing using different enhancement tools. (a) Sharpness; (b) pseudo-3D; (c) reverse-contrast.

Weighted kappa coefficients were calculated to assess intra- and inter-observer agreement for each image set. Scores obtained from original, sharpness, zoom-in (magnification), reverse-contrast and pseudo-3D digital images were compared with the gold standard using receiver operating characteristic (ROC) analysis to evaluate observer ability in differentiating between teeth with and without VRF. The areas under the ROC curves (Az values) were calculated using the MedCalc statistical software (MedCalc Software, Mariakerke, Belgium) and the Az values for each image type, observer and reading were compared using *t*-tests. A level of $\alpha = 0.05$ was considered significant.

Results

Table 1 shows the kappa coefficients calculated for each observer. Intra-observer kappa coefficients ranged from 0.304 to 0.679. Observer 1 (oral radiologist) had the best intra-observer kappa coefficients (between 0.501 and 0.679), suggesting moderate-to-good agreement. Fair inter-observer agreement was found for both the 1st and 2nd readings (Table 2). The areas under the ROC curves (Az values) for the different observers, readings and image types are given in Table 3. No significant differences ($P > 0.05$) were found in Az values for the different observers, readings or image types. Figure 4 shows the ROC curves for observer 1 for the first reading for all image sets. All images performed similarly, suggesting that the use of image enhancement filters did not increase diagnostic value or observer agreement.

Table 1. Weighted kappa coefficients for intra-observer agreement

	Observer 1	Observer 2	Observer 3
	Weighted kappa (SE)	Weighted kappa (SE)	Weighted kappa (SE)
Original	0.501 (0.084)	0.371 (0.089)	0.478 (0.079)
Sharpness	0.611 (0.073)	0.327 (0.091)	0.475 (0.089)
Zoom	0.649 (0.067)	0.441 (0.077)	0.552 (0.086)
Reverse-contrast	0.679 (0.071)	0.339 (0.106)	0.549 (0.067)
Pseudo 3D	0.597 (0.087)	0.304 (0.091)	0.370 (0.084)

Discussion

The diagnostic value of the different enhancement tools provided with digital imaging software packages is controversial. Not only are digital system enhancement tools task-specific, but also their efficacy is known to depend upon observer experience, which makes them subjective diagnostic tools. This study compared the use of differently enhanced CCD images in the detection of vertical root fractures by three observers. In the present study, no soft-tissue equivalent was used. Besides, images obtained from only one ortho-radial projection was utilized. It is possible that images taken from three different angulations could increase detection ability. In a study in which vertically fractured endodontically treated teeth were evaluated clinically and radiographically before and after extraction, general practitioners were able to correctly diagnose the fractures in only one-third of 92 teeth (3). In clinical practice, the use of periapical radiographs for the detection of VRF is complicated by the bucco-lingual orientation of the

Table 2. Weighted kappa coefficients for inter-observer agreement for1st and 2nd readings

	1st reading			2nd reading		
	Obs 1 & Obs 2	Obs 1 & Obs 3	Obs 2 & Obs 3	Obs 1 & Obs 2	Obs 1 & Obs 3	Obs 2 & Obs 3
	Weighted kappa (SE)	Weighted kappa (SE)	Weighted kappa (SE)	Weighted kappa (SE)	Weighted kappa (SE)	Weighted kappa (SE)
Original	0.109 (0.091)	0.129 (0.097)	0.399 (0.084)	0.296 (0.091)	0.301 (0.085)	0.360 (0.091)
Sharpness	0.193 (0.097)	0.214 (0.092)	0.328 (0.085)	0.126 (0.099)	0.285 (0.087)	0.380 (0.091)
Zoom	0.254 (0.094)	0.216 (0.100)	0.279 (0.083)	0.239 (0.086)	0.313 (0.087)	0.336 (0.088)
Reverse-contrast	0.280 (0.112)	0.221 (0.079)	0.233 (0.086)	0.158 (0.111)	0.108 (0.078)	0.106 (0.092)
Pseudo 3D	0.130 (0.066)	0.150 (0.071)	0.214 (0.088)	0.244 (0.081)	0.115 (0.064)	0.345 (0.082)

Table 3. Area under the ROC curve values (Az values), their standard errors (SE) and statistically significant values (*P*) for each observer and their two readings

	Observer 1		Observer 2		Observer 3	
	1st reading	2nd reading	1st reading	2nd reading	1st reading	2nd reading
	Az (SE) *P*	Az (SE) *P*	Az (SE) *P*	Az (SE) *P*	Az (SE) *P*	Az (SE) *P*
Original	0.700 (0.066) 0.0023	0.740 (0.062) 0.0001	0.520 (0.073) 0.7881	0.710 (0.065) 0.0012	0.560 (0.072) 0.4087	0.709 (0.065) 0.0013
Sharpness	0.759 (0.060) 0.0001	0.787 (0.057) 0.0001	0.628 (0.070) 0.0658	0.660 (0.068) 0.0187	0.651 (0.069) 0.0280	0.789 (0.057) 0.0001
Zoom	0.720 (0.064) 0.0006	0.776 (0.059) 0.0001	0.648 (0.069) 0.0316	0.649 (0.069) 0.0297	0.683 (0.067) 0.0062	0.797 (0.056) 0.0001
Reverse-contrast	0.689 (0.066) 0.0042	0.700 (0.066) 0.0023	0.627 (0.070) 0.0692	0.614 (0.070) 0.1046	0.621 (0.070) 0.0855	0.708 (0.065) 0.0013
Pseudo 3D	0.683 (0.067) 0.0062	0.676 (0.067) 0.0087	0.565 (0.072) 0.3670	0.757 (0.061) 0.0001	0.603 (0.071) 0.1479	0.694 (0.066) 0.0033

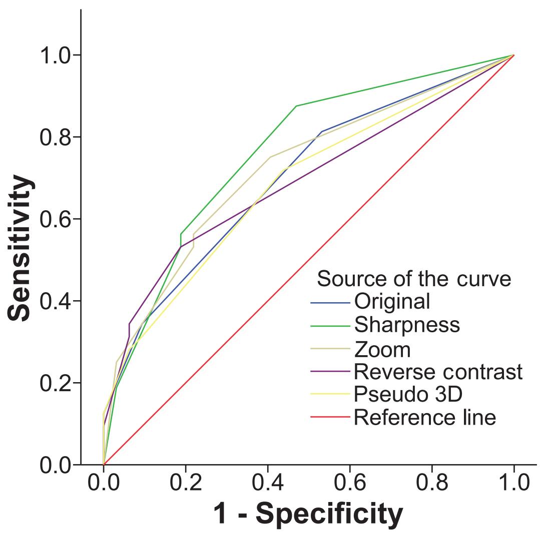

Fig. 4. ROC curves for the first reading of observer 1 for the different image types.

fracture line and the masking effects of root-canal fillings, pins and posts.

The present study is consistent with an earlier study that showed no significant improvements in the detection of VRF using the zoom function at 1:1, 1:2, and 2:1 digital magnifications (12). Our findings are analogous to another study which found that none of the filters improved the diagnostic outcome in digital images which did not show clearly visible root fractures before application of eight different convolution filters (14). In a study examining the detection of artificially induced internal resorption using different image types, CMOS Schick CDR Revealer and contrast-inverted Sopix wireless CCD images resulted in the highest percentage of correct readings; however, the differences were not statistically significant (15). Another study found no differences in determining the accuracy of working length using D- and F-Speed films, Schick CDR and Schick CDR with Revealer, although subjective ratings showed an observer preference for enhanced digital images (16). A number of different enhancement features have been evaluated for their effects on caries detection, but none of them has demonstrated any statistically significant improvement in diagnostic ability. Kositbowornchai et al. found the use of sharpness, zoom and pseudo-colour functions provided no additional diagnostic value in the detection of occlusal caries (17). In another study, digitized images enhanced by inversion, histogram-averaging, high-pass, mean-value and spreading of grey values did not result in any statistically significant improvements over unenhanced digitized images in the reproducibility or validity of caries depth measurements (18). Another study found no improvements in diagnostic accuracy when caries-specific processing algorithms were used instead of the default algorithm of a storage phosphor system (19). Although Moystad et al. found a reduction in inter-observer and intra-observer variability using the 'caries-specific Oslo enhancement procedure,' diagnostic outcome was not considered statistically significant (20). In the present study, enhancement of digital images did not result in any significant improvements in intra- or inter-observer agreement in the detection of VRF.

Some studies have found the use of image enhancements to improve diagnoses in different situations. Contrast and brightness features were found to be the most effective in increasing the ability to detect periapical lesions, although the effect was limited (21). Enhancements of density, contrast and edges have been shown to improve caries detection, especially with low-density images (22). Inverted, contrast/brightness and edge enhancement algorithms have also been recommended for improving accuracy in determining file-length measurements using storage phosphor plates (23).

In contrast, some studies have found diagnostic accuracy to decrease when image enhancements are used. In one study, image reduction was shown to result in a loss of diagnostic information used to monitor endodontic file-length (24). Other studies have shown enhanced images to have lower diagnostic accuracy than unenhanced images in caries detection (25, 26). Reverse-contrast direct digital radiography (DDR) images have also been found to be inferior to DDR stored images, DDR transmitted images and D-speed film in the detection of artificial periapical lesions (27).

Conclusion

This study found that the use of visual enhancement tools had no effect on diagnostic outcome, intra-observer agreement, or inter-observer agreement in the *in vitro* detection of VRF. To obtain the most diagnostic benefit from specific enhancement features, their limitations, advantages and disadvantages need to be well-known. For this reason, further studies are needed to evaluate the effectiveness of different enhancement tools for various diagnostic purposes. In addition, processing algorithms can be developed for task-specific root fracture detection in contemporary digital intra-oral modalities.

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