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Original Article

Accuracy of digital image enhancement in detection of vertical and horizontal root fracture

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ABSTRACT

Background: Two-dimensional intraoral radiography is the most common tool for recognizing root fractures. Improving the quality of images by means of enhancement tools can increase the recognition power of them. The aim of this study is to evaluate the effect of digital image enhancement on vertical and horizontal root fractures (HRFs) diagnostic accuracy.

Materials and Methods: In this *in vitro* study, 100 human extracted teeth, involving 50 mandibular premolars and 50 maxillary incisors, were investigated. In total, 25 premolar teeth were vertically fractured and other 25 sound teeth served as testing group. According to the verified methods, 25 incisor teeth were fractured and other 25 teeth of this group served as testing ones. Following, by using the charge-coupled device sensor, preapical digital images were recorded. The original images were altered using reverse-contrast and colorization enhancement tools. Two different observers independently investigated all of the images. Receiver operating characteristic analysis was used to calculate the area under the curve (AUC) and sensitivity and specificity of all images. Data analyzde using receiver operating characteristic (ROC) analysis. Two-ways variance analysis was used to assess differences in the values ($P = 0.05$).

Results: AUC and sensitivity and specificity related to the original, reverse-contrast, and colorized images were calculated (0.84, 0.64, 0.99), (0.84, 0.64, 0.96), and (0.82, 0.64, 0.92) respectively, for vertically root fractured images. AUC and sensitivity and specificity related to the original, reverse-contrast, and colorized images were calculated (0.49, 0.44, 0.56), (0.50, 0.44, 0.60), and (0.48, 0.48, 0.48), respectively, for horizontally root-fractured images.

Conclusion: The results of the present study revealed that reverse-contrast and colorized enhancement filters cannot be used as critical methods in detecting *in vitro* vertical and HRF.

Key Words: Digital radiography, endodontics, root fracture

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INTRODUCTION

Root fractures involve 0.5%–7% of injuries.[1] Regarding the permanent dentition and compared to other dental traumas, root fractures are relatively uncommon. However, root fracture often leads to tooth extraction.[2,3] Depends on the direction of line to the long axis of the tooth, root fractures are usually horizontal, vertical, and oblique.[1]

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Horizontal root fractures (HRF's) often occur in fully erupted teeth with complete root formation. HRF's can be seen in the maxillary anterior tooth in male patients frequently.[2,4] The middle third of the root is usually affected through HRF's.[5] The prognosis of the involved tooth is influenced by several factors such as stage of root formation, age of the patient, degree of dislocation and mobility of the coronal segment, and width of dislocation between the segments.[2,4,6] Diagnosis of HRF's is based on the mobility of the coronal segment of the tooth and radiographic manifestation of a fracture line or lines. Usually, to diagnose HRF`s, two or three radiographs are taken at various angles.[1,2]

A true vertical root fracture (VRF) is a longitudinal fracture that is confined to the root. It is usually initiated on the internal canal wall and is extended outward to the root surface.[1] The major etiological factor for VRF is root canal treatment. The insertion of screws or posts in a root after endodontic treatment can cause VRF too.[1-3] Diagnose of this condition is usually difficult and need tooth extraction. VRFs are associated with various problems including pain, swelling, mobility, isolated periodontal pockets, and sinus tracts.[7-9]

VRF can lead to the development of bony lesions, which cause problems in placement of implant in that region. The radiographs can show the perilateral radiolucency and angular resorption of the crestal bone.[10]

Early diagnosis of root fracture is an important process for preventing extensive damage to the supporting tissue, extracting the affected tooth, determining the prognosis of an individual tooth, and choosing the appropriate treatment.[11]

The digital two-dimensional (2D) radiography is the most common diagnostic tool for detection of root fracture.[11-14] Nowadays, because of lower levels of patient's radiation dose and faster imaging time, the traditional films are replaced by digital imaging systems.[15] To detect a root fracture, the X-ray beam must pass directly along the fracture line.

To improve the visual quality of diagnostic images, postprocessing is done on images by enhancement tools.[16] Reverse contrast is an electronic image processing tool which produces a radiographic negative image from the radiographic positive image. Since humans can distinguish colors better than shades of gray, transforming the gray values of a digital image to various colors may enhance the detection of objects within the image.[17]

The enhancement tools' results are more attracting images visually. However, there is no scientific evidence, suggesting that they can increase diagnostic values.[10,18,19]

This study focuses on determining the effects of employing image enhancement features on detecting vertical and HRFs from digital images.

MATERIALS AND METHODS

Phantom preparation

The Ethics Committee of Isfahan University of Medical Sciences approved this analytical cross-sectional study (395918).

In this *in vitro* study, 100 extracted human single-root teeth including 50 mandibular premolars and 50 maxillary incisors (central and lateral), without root fractures and root-canal treatment, were used. Extraction was performed because of caries, periodontitis, alveolar bone loss, ectopic localization, and orthodontic indication. Teeth were completely sound without fractures, internal or external resorption, and acutely curved roots. The absence of cracks, fractures, and caries on the root surfaces were confirmed with stereomicroscopy (PICL-NBX, Nikon, Tokyo, Japan) at × 20. The teeth were placed in a 1% hypochlorite solution overnight. Then, they were stored in distilled water.

All of the teeth were divided into two groups: premolars and incisors. In the first group (including premolars), access cavity was performed coronally with a diamond bur and was prepared with stainless steel K-file numbers 15–45 and irrigated with saline. Canals were filled with gutta-percha. The fillings were removed up to the apical two-thirds using a No. 4, 5 Gates Glidden drill. We numbered all of the teeth and then divided them into two groups: In 25 teeth, as test group, VRFs were created using controlled gently tapping hammer and conical wedge until a sharp "cracking" sound was heard. We excluded the segmented teeth from the study and replaced them.

To be sure about the existence of hairline fractures, the roots were investigated by stereomicroscopy at ×20 again. The remaining 25 intact teeth served as controls.

In the second group (including incisors), after giving the numbers, HRFs were created in 25 teeth by a mechanical force using a hammer, while the teeth were placed on a soft foundation as described in a previous study.[20] Then, two root fragments were glued together with one layer of methyl methacrylate. The remaining 25 intact teeth served as controls.

Following, we placed all of the teeth in the empty mandibular premolar and maxillary incisor sockets of a dry specimen randomly.

Radiographic data acquisition

All of the radiographs were taken by Planmeca dental X-ray unit (Planmeca, Helsinki, Finland) that was operated in 65 kVp, 7 mA. The radiographs were recorded using a charge-coupled device (CCD) direct digital intraoral sensor size 2 (Dr. Suni, Suni Imaging, San Jose, CA, USA).

Density and contrast of all radiographs were similar. Focus-object distance was 20 cm and the long axis of object was parallel to the receptor. To simulate the soft tissue, an acrylic plate (Acropars, cold cure acrylic, MARLIC medical industries co, Iran) with 2 cm thickness was placed between X-ray tube and specimen. All of the images were captured and stored using Cygnus media software. Then, reverse-contrast and colorized images from original image by one researcher were set [Figures 1 and 2]. In Figure 1, the root fractures in the fractured teeth are extended as vertical cracks along the root in all three images and are reached to the exterior sidewall of the teeth. In Figure 2, the root fracture in the fractured teeth can be seen as a horizontal line in the root.

Image assessment

Two calibrated observers (two oral radiologists) evaluated the original, reverse-contrast, and colorized images separately to detect the presence of the fracture lines.

Digital radiographs were evaluated randomly in dimly lit room on a LG 22-inch high-quality monitor with screen resolution set at 1440 × 6900 pixels and color set to 32-bit depth. To eliminate memory bias and to estimate intraobserver agreement each observer evaluated the images twice with 2 weeks interval. The observation time was not limited and observers were allowed to change brightness, contrast, and density of images.

The observers classified fracture presence according to a five-point scale: 1 = definitely absent, 2 = probably absent, 3 = uncertain, 4 = probably present, and 5 = definitely present.

Statistical analysis

Data were analyzed using SPSS version 24.0 (IBM SPSS, Chicago, IL, USA). Intra- and inter-observer agreements were calculated using the weighted Kappa test. The values obtained from original, reverse-contrast, and colorized digital images were compared with the gold standard using receiver operating characteristic (ROC) analysis. In addition, sensitivity and specificity were calculated too.

Two-ways variance analysis was used to assess differences in the values. The level of significance was set at $\alpha = 0.05$.

RESULTS

The kappa coefficient, which is calculated for each image, is presented in Table 1. In Accordance with Landis and Koch classification,[21] intraobserver was

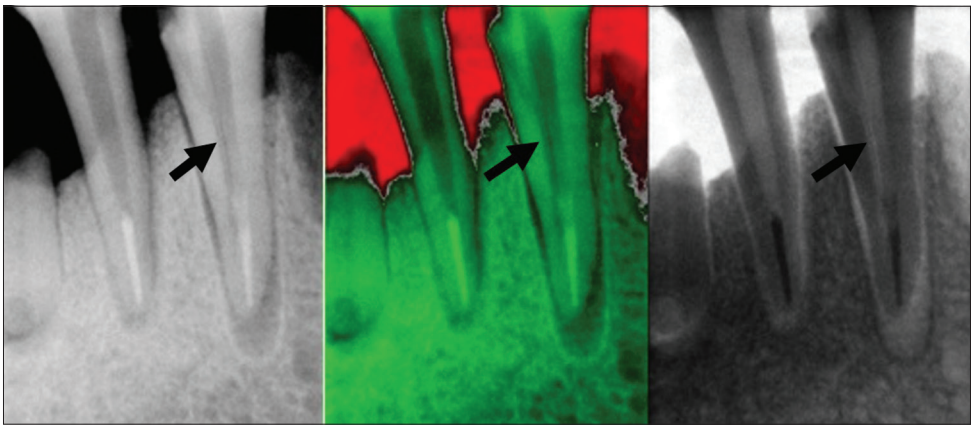

Figure 1: Original, colorized, and reverse-contrast images that are created from two premolar teeth; intact (the left tooth) and fractured (the right tooth). The arrows show the fractured lines.

Table 1: Kappa values for intraobserver and interobserver agreement

Fracture type	Image type	Intraobserver			
		First observer	Second observer	First reading	Second reading
Vertical	Original	0.892	0.778	0.357	0.384
	Reverse-contrast	0.777	0.793	0.417	0.369
	Colorization	0.861	0.746	0.271	0.320
Horizontal	Original	0.791	0.814	0.368	0.446
	Reverse-contrast	0.747	0.741	0.465	0.463
	Colorization	0.760	0.832	0.414	0.483

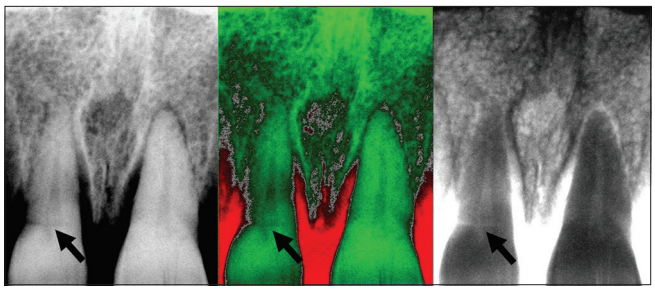

Figure 2: Original, colorized, and reverse-contrast images that are created from two incisor teeth; intact (the right tooth) and fractured (the left tooth). The arrows show the fractured lines.

substantial in reverse-contrast (VRF and HRF) images and almost perfect in all other images. Interobserver was fair in original and colorization (VRF), fair to moderate in reverse-contrast (VRF) and original (HRF), and moderate in reverse-contrast and colorization (HRF) images.

The values of sensitivity and specificity and areas under the ROC curves are given in Table 2. We found no significant differences in values for the different images using analysis of variance ($P > 0.05$). Subsequently, all images were performed similarly, suggesting that the use of image enhancement filters did not increase diagnostic value or observer agreement.

DISCUSSION

In this study, we investigate the effects of enhancing methods in digital images on the diagnosis accuracy of horizontal and VRFs compared to original images.

Low interobserver agreement was found that showed the diagnosis of root fracture with periapical radiographs is difficult. The results are in accordance with other studies that reported low levels of intra- and inter-observer agreement.[10,22-24]

Temporomandibular-joint and teeth are the most common site for absorbing the trauma and fracture. True diagnosing and proper treatment of dental fracture prevent the next consequences like bone loss.[25,26] There were various aspects of employing digital image enhancement in dentistry such as diagnosing different kinds of caries,[27-30] bone loss,[31] file and root canal length measurements,[22] and VRF.[10,32,33] However, studies about image enhancement in HRF were scarce.

Reviewing literatures reveal that the results about employing enhancement tools conflict with each other. Some studies showed that image enhancement improved the diagnostic accuracy of VRF.[25,33] On the contrary, other studies showed that diagnose accuracy in enhanced images did not differ with unenhanced ones (such as this study).[10,34] The reasons of differences can be as follows:

There are various kinds of enhancement filters, which can be used for special diagnostic purposes. In this study, we used reverse contrast and colorization. The results showed that these filters were not critical for root fracture diagnosis. However, other studies showed that employing other enhancement filters such as sharpen filter, contrast, brightness, and Gamma curve can be helpful in detecting root fractures and occlusal and approximation caries.[33,35]

- The second main reason of difference can be the digital image system with difference resolutions:

Bechara *et al*. compared cone-beam computed tomography (CBCT) with phosphor stimulated plate (PSP)- enhanced images in detection root fractures. The result showed that PSP-enhanced images have the same accuracy with images of small field of view CBCT, and they were more accurate than large field of view CBCT images.[3] Nascimento *et al*. showed among shadow, 3D emboss, negative and sharpness enhancement tools, and using sharpen filter in Digora Optime system with PSP sensor can improve VRF radiographic diagnosis.[33] Moystad *et al*. showed comparing unenhanced and E-speed films, enhancement of storage phosphor image improves the approximal caries diagnostics.[36] Kamburoğlu *et al*. and Tofangchiha *et al*. investigated VRF by CCD

Table 2: Mean diagnostic values for image types

Fracture type	Image type	Sensitivity	Specificity	Area under ROC curve
Vertical	Original	0.64	0.99	0.84
	Reverse-contrast	0.64	0.96	0.84
	Colorization	0.64	0.92	0.82
Horizontal	Original	0.44	0.56	0.49
	Reverse-contrast	0.44	0.60	0.50
	Colorization	0.48	0.48	0.48

ROC: Receiver operating characteristic

digital system. They utilized enhancement filters and showed these filters did not affect diagnostic results.[10,25] Their findings are in accordance with the results of this paper.

- The other reason can be various methods of fracture creating, in which each one can create fractures with different width. In this study, we tried to create VRFs just as cracks. In addition, we excluded the segments, which have been parted through fracture process from the study. Most of the *in vitro* studies induced complete VRFs with the fragments being repositioned and bonded[10,25,34,36-38]
- Tofangchiha *et al*. in their study showed that colorization could be more sensitive compared to the reverse contrast for VRFs detection.[25] The reason for difference between two studies is that for more simulation with *in vivo* condition, we placed the teeth in the mandibular socket, and the soft tissue was simulated. It causes more attenuation of X-ray and hence decreases resolution. It can also create new boundaries for colorization
- The results of some literature reveal that the performance of CBCT in detecting VRFs is better compare to other 2D image modalities.[2,10,36] However, recent studies reported no significant difference between CBCT and periapical radiographs.[15,38-40] On the other hand, recent increasing development of digital systems and postprocessing software would improve dental disease detection. According to SEDENTEXCT guidelines, if both the clinical and conventional radiographic data do not provide enough information for the diagnosis of root fracture, CBCT should be indicated.[41] However, it must be mentioned that the radiation dose and cost of the CBCT examination are higher compared to periapical radiograph.

One of the purposes of this study was to show whether enhanced images, acquisition in one X-ray tube angle, can be helpful in horizontal fracture detecting. Low levels of sensitivity and specificity are the results of much more dependency of horizontal fracture diagnose upon the vertical angulation of X-ray tube. In this study, we used 0° angle in horizontal and vertical imaging.

In the present study, we minimized variability in study conditions and tried to mimic the clinical situation (such as exclusion segmented teeth from study or investigating hairline fracture by stereomicroscope), but the depth of the root fractures cannot be same even we used same force because the resistance of the teeth is different. So, differences arose between *in vitro* and *in vivo* detection of root fractures invariably. In this study, single-rooted teeth were used to detect VRFs. Hence, the next study about multirooted teeth is suggested. Furthermore, images of root fractures were recorded just in one angle. The study of the image enhancement effects in different angles on the horizontal fracture recognition accuracy can be a worthy study. On the other hand, the main limitation of these kinds of research is that they are *in vitro* situations and are different with *in vivo* conditions. A similar study in *in vivo* condition is suggested.

CONCLUSION

This study showed that utilizing reverse-contrast and colorization digital images would not help diagnosing horizontal and VRFs.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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