Accuracy of Digital Subtraction Radiography in the Detection of Vertical Root Fractures

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Abstract

Introduction: The objective of this study was to evaluate the accuracy of digital subtraction radiography in the diagnosis of vertical root fractures (VRFs). Methods: Twenty decoronated uniradicular human teeth were placed in the alveoli of a dry mandible and radiographed twice, first without (unfilled roots) and then with (filled roots) a gutta-percha cone placed into the root canal. Roots were then removed from the dry mandible, and vertical fractures were created with the aid of a universal testing machine. The fractured roots were repositioned in the mandibular alveoli and again radiographed twice. Digital radiographic images were subtracted by using the Regeemy software in 3 test situations: group 1, initial radiographic images of unfilled roots and images of fractured or non-fractured unfilled roots; group 2, initial radiographic images of unfilled roots and images of fractured or non-fractured filled roots; and group 3, initial radiographic images of filled roots and images of fractured or non-fractured filled roots. Three examiners evaluated all the original digital radiographs, as well as the subtracted images, for the presence or absence of VRFs. Numerical data were subject to statistical analysis with the use of receiver operator characteristic (ROC) curves. Results: The areas under the ROC curve for groups 1, 2, and 3 were 0.86, 0.73, and 0.66, respectively. For the original digital radiographs, areas under the ROC curve were 0.80 (without gutta-percha) and 0.73 (with gutta-percha). No statistically significant differences were found between subtracted and original images. Conclusions: Digital subtraction radiography could be considered as an alternative tool for the investigation of VRFs because of its comparable diagnostic accuracy to existing methods. (J Endod 2016;42:896–899)

Key Words
Digital subtraction radiography (DSR), radiography, vertical root fracture

Digital subtraction radiography (DSR) is an imaging technique that determines qualitative changes between 2 radiographs taken at different times. The subtracted image is colored in neutral gray and reveals features that differ between the first and the second images (1). For instance, areas of mineral tissue loss are usually dark gray, whereas areas of mineral apposition appear as light gray (2).

DSR analysis uses serial images of similar geometric contrast and density to detect subtle visual changes (3). In the early 1980s, algorithm-based image reconstruction software was developed to project images so that the best possible superimposition could be obtained. Among those, the Regeemy suite is offered free of charge for scientific and diagnostic use; in addition, it provides both automatic and manual selection of landmarks for geometric reconstruction. Therefore, this software has been widely used in studies involving the DSR technique (4–6).

Radiography is the most commonly used imaging modality for the diagnosis of vertical root fractures (VRFs) (7). Although clinical and radiographic diagnoses of VRFs are challenging tasks for the general dentist (8), they are essential to avoid unnecessary tooth extractions (9). On a radiograph, a VRF is identified as a vertical radiolucent line that is visible only if the x-ray beam parallels the plane of fracture (10). Endodontically treated teeth are at higher risk of experiencing VRFs than vital teeth, most likely because of excessive root canal instrumentation, excessive pressure during gutta-percha filling, or inappropriate placement of intraradicular posts (11).

In the scientific and clinical settings, DSR has been used to assess dental and bone density, post-fracture mandibular bone healing and alveolar bone tissue alterations, as well as to diagnose proximal caries (1, 6, 12–14). Surprisingly, studies that use DSR for the detection of VRFs are very scarce. Considering that endodontic treatment is the major predisposing factor for VRFs and that radiographic examination is an essential component of proper endodontics (15), DSR could be a valid and easily implemented method for root fracture diagnosis. Therefore, the aim of this study was to evaluate the accuracy of DSR in the context of VRF diagnosis.

Materials and Methods

Sample Preparation and Image Acquisition

The local Research Ethics Committee reviewed and approved this work without restrictions (Protocol no. 054/2014). Twenty uniradicular human teeth were disinfected for 2 hours in a 2% glutaraldehyde solution. Subsequently, all crowns were sectioned near or at the cementoenamel junction by using a diamond disk cutter (IsoMet 1000; Buehler Ltd, Lake Bluff, IL), and root length was standardized at 15 mm from the root apex. Chemical and mechanical root canal preparation was performed with the rotary system ProTaper Universal (Dentsply, Tulsa, OK) as proposed by the manufacturer. To standardize dentin removal, apical preparation was performed with the F2...
(25.08) file in all roots. The roots were irrigated with saline after every file change. After instrumentation, an F2 (Dentsply) gutta-percha cone was placed in the canal for radiographic acquisition. Pencil marks made on the buccal surfaces of all roots ensured that they were properly repositioned in the alveoli before being radiographed.

All radiographs were obtained with a GX-770 periapical machine (Gendex Dental Systems, Lake Zurich, IL; 70 kVp, 7 mA, exposure time 0.08 seconds), VistaScan phosphor plates (size 2, 30 x 40 mm active area), and the DBSWIN software (Dürr Dental, Bietigheim-Bissingen, Germany). For the initial radiographic images (non-fractured/unfilled image set), each prepared root was placed in the alveoli of the premolar region of a human dry mandible. Radiographs were taken in an orthoradial incidence (0° horizontal and vertical angles indicated by a protractor) with the aid of a custom holder designed to maintain the specimen, the film-holding device, and the image receptor in a reproducible relationship. To simulate soft tissue attenuation, a 2.5-cm-thick acrylic plate was placed in front of the specimens. Then an F2 gutta-percha cone was introduced into the root canal, and new periapical radiographs were obtained as described above to form the non-fractured/filled group image set.

Roots were then removed from the alveoli, and VRFs were created with a universal testing machine (ISTRON 4411; Instron Corp, Canton, MA). In brief, a tapered metal tip placed at the entrance of the root canal was programmed to push into the canal at a speed of 1 mm/min and 500 N, stopping automatically once the fracture occurred. Although fracture width was not controlled, root fragments were not displaced and thereby mimicked a thin-line fracture. After fracture creation, roots were repositioned in the alveoli for radiographic acquisition as described above, forming the fractured/unfilled image set. After the insertion of gutta-percha cones into the root canals, radiographs were acquired to create the fractured/filled image set.

Subtraction of Radiographic Images

Radiographic images were subtracted by using the Regeemy software (Image Registration and Mosaicking version 0.2.43; DPI-INPE, São José dos Campos, São Paulo, Brazil and Vision Lab–Electrical and Computer Engineering Department, University of California, Santa Barbara, CA). First, the initial radiographic image (non-fractured/unfilled) was opened as image 1. Then the corresponding image of the same root with 1 of the tested conditions (fracture and/or filling) was opened as image 2. Subsequently, the subtraction image tool was applied to create the subtracted image. The images were shown over a neutral gray background, with dark areas corresponding to density loss (fracture) and light areas corresponding to density gain (filling material). The resulting images were saved as TIFF (Tagged Image File Format) files.

Subtracted images were grouped as follows:

**Group 1:** Radiographic images of unfilled and fractured or non-fractured roots were subtracted from the initial radiographic images.

**Group 2:** Radiographic images of filled and fractured or non-fractured roots were subtracted from the initial radiographic images.

**Group 3:** Radiographic images of filled and fractured or non-fractured roots were subtracted from the initial radiographic images of filled roots.

In addition, the following 2 groups made of the initial radiographic images were created for comparison with the subtracted ones:

**Group 4:** Radiographic images of unfilled and fractured or non-fractured roots

**Group 5:** Radiographic images of filled and fractured or non-fractured roots

**Figure 1** shows examples of the subtracted images obtained.

**Image Assessment**

To check the effectiveness of DSR in VRF diagnosis, the subtracted images were randomized in a PowerPoint (Microsoft Corp, Redmond, WA) presentation with a black background and then evaluated by 3 calibrated examiners. The examiners classified fracture presence according to a 5-point scale: 1, definitely absent; 2, probably absent; 3, uncertain; 4, probably present; and 5, definitely present. After
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30 days, one fourth of the sample was reassessed. The initial radiographic images (groups 4 and 5) were evaluated in the same way.

Statistical Analysis

Statistical analysis was performed by using SPSS version 17.0 (SPSS Inc, Chicago, IL). Intraobserver and interobserver reproducibility was evaluated by using the weighted kappa test. The scores were compared with the gold standard by using the receiver operating characteristics (ROC) curve. Areas under ROC curve for each observer were obtained. Moreover, sensitivity and specificity were calculated. The values were compared by one-way analysis of variance with the post hoc Tukey test. A significance level of 5% was used for all analysis.

Results

The values for sensitivity, specificity, and areas under the ROC curve are shown in Table 1. Sensitivity was highest in group 1, followed by groups 4, 3, 5, and 2. Specificity too was highest in group 1, followed by groups 3, 4, and 5 with similar values and group 2. Areas under the ROC curve were highest in group 1, followed by group 4, groups 3 and 5 with similar values, and group 2. However, analysis of variance showed that there was no significant difference between subtracted and original images.

The range of kappa values for each group is presented in Table 2. According to the classification proposed by Landis and Koch (16), intraobserver and interobserver reproducibility was moderate to substantial and fair to substantial in groups 1 and 5, almost perfect and slight to moderate in group 2, slight to almost perfect and slight to fair in group 3, and almost perfect and substantial in group 4, respectively.

Discussion

As far as our scrutiny of the available literature could go, it seems that the present work is the first to evaluate the use of DSR in VRF diagnosis. VRF is a condition that must be diagnosed early to prevent alveolar bone loss and resorption (17). Unfortunately, periapical radiographs can only be of diagnostic value if the x-ray beam parallels the plane of fracture. Because VRF occurs mainly in endodontically treated teeth, the presence of filling materials renders the diagnostic process even more complex (8, 10).

Most of the difficulty in diagnosing VRFs with periapical radiographs resides in image overlapping (18); on the other hand, artifacts generated by root-filling materials (19–21) may cause trouble with cone-beam computed tomography (CBCT)—based diagnosis. Thus, there is a clear need for an alternative imaging technique that simplifies VRF identification.

Several studies have used radiographic subtraction to assess other dental and maxillofacial conditions (1, 4, 6, 12–14). Their conclusions seem that the present work is the first to evaluate the use of DSR for detecting VRF. One advantage of DSR is a valuable diagnostic aid. Here the accuracy of dental and maxillofacial conditions(1, 4, 6, 12–14). Their conclusions VRF identification. There is a clear need for an alternative imaging technique that simplifies periapical radiographs can only be of diagnostic value if the x-ray.

The ROC curve is the most useful method to compare the diagnostic performance of imaging modalities (30). An area of 1 is considered a perfect mark, whereas one around 0.5 represents a poor result (31). When we compared DSR and digital radiography in terms of the area under the ROC curve, numbers were similar.

CBCT is one contemporary tool for VRF diagnosis. This imaging technique allows for 3-dimensional reconstruction of the anatomic structures and therefore eliminates image overlapping. If the dental roots are filled with gutta-percha or metal posts, however, artifacts may prevent the identification of root fracture lines (19–21, 25). Furthermore, according to the SEDENTEXCT (32) and the European Society of Endodontontology position statement (33) guidelines, CBCT images must be used only if one judges that periapical radiographs do not provide enough information for VRF diagnosis.

Geometrical registration in the context of DSR can be manual (14) or automatized (22). The software used in this study (Regeemy) offers a tool for automatic selection of landmarks for geometric reconstruction.

The low interobserver kappa values regarding filled roots found in this study reflect the difficulty of diagnosing VRFs with periapical radiographs and are in accordance with other studies that reported low levels of intraobserver and interobserver agreement (8, 9).

No endodontic sealer was used with the gutta-percha intracanal filling because the cement could separate the root fragments and fill the spaces between them, rendering VRF diagnosis obvious (9, 23, 24). Interestingly, absence of filling material (groups 1 and 4) made the distinction between fracture presence (sensitivity) and absence (specificity) easier. Previous studies that used other assessment methods such as periapical radiography and CBCT showed similar results when assessing root fractures in non-filled roots (8, 19, 25–27).

On the other hand, specificity was higher than sensitivity in the groups with filled roots. It may be that examiners are more likely to regard fractures as absent when visualization is affected by the filling material, which in turn could falsely increase the number of correct answers for images without fracture. These results are similar to other studies in which sensitivity was lower in the presence of root-filling materials (8–10, 26–29). Moreover, a lower specificity can be explained by the presence of intracanal posts, which may superpose and mask the fracture line. Naturally, specificity will be high because the number of non-detected fracture cases will be larger than that of detected ones.

Unfortunately, most VRFs occur in teeth with filled roots. Therefore, fracture visualization is difficult because of superposition of the fracture line by the filling material. Even in more advanced imaging methods such as CBCT, the presence of gutta-percha or metal posts decreases diagnostic accuracy (9, 19). Thus, the challenge of a correct diagnosis for VRFs persists regardless of the imaging modality that one uses. Here we tested a new technique in an attempt to minimize this problem and proved that DSR can be a suitable tool for diagnosing VRFs depending on the professional’s preference, despite our findings that showed that DSR did not differ from digital radiography in terms of diagnostic accuracy, as reported elsewhere for the detection of apical root resorption (4).

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Considering our results and the low radiation involved when one chooses to use the DSR technique, this approach appears to be of good clinical value for dental practitioners. With future advancements in DSR technology, automated computer diagnostic systems that display the results immediately after image acquisition may be devised for the detection of VRFs and other challenging conditions (14).

**Conclusion**

Because of its acceptable diagnostic accuracy and low radiation requirements, DSR is an imaging modality that clinicians and oral radiologists could consider when suspicious of the existence of a VRF.

**Acknowledgments**

This work was supported by grants-in-aid from CAPES, Brazil. The authors deny any conflicts related to this study.

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