

RESEARCH ARTICLE

Influence of cone beam CT enhancement filters on diagnosis ability of longitudinal root fractures

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Objectives: To determine whether cone beam CT (CBCT) enhancement filters influence the diagnosis of longitudinal root fractures.

Methods: 40 extracted human posterior teeth were endodontically prepared, and fractures with no separation of fragments were made in 20 teeth of this sample. The teeth were placed in a dry mandible and scanned using a Classic i-CAT® CBCT device (Imaging Sciences International, Inc., Hatfield, PA). Evaluations were performed with and without CBCT filters (Sharpen Mild, Sharpen Super Mild, S9, Sharpen, Sharpen 3 × 3, Angio Sharpen Medium 5 × 5, Angio Sharpen High 5 × 5 and Shadow 3 × 3) by three oral radiologists. Inter- and intraobserver agreement was calculated by the kappa test. Accuracy, sensitivity, specificity and positive and negative predictive values were determined. McNemar test was applied for agreement between all images vs the gold standard and original images vs images with filters ($p < 0.05$).

Results: Means of intraobserver agreement ranged from good to excellent. Angio Sharpen Medium 5 × 5 filter obtained the highest positive predictive value (80.0%) and specificity value (76.5%). Angio Sharpen High 5 × 5 filter obtained the highest sensitivity (78.9%) and accuracy (77.5%) value. Negative predictive value was the highest (82.9%) for S9 filter. The McNemar test showed no statistically significant differences between images with and without CBCT filters ($p > 0.05$).

Conclusions: Although no statistical differences was observed in the diagnosis of root fractures when using filters, these filters seem to improve diagnostic capacity for longitudinal root fractures. Further *in vitro* studies with endodontic-treated teeth and research *in vivo* should be considered.

Dentomaxillofacial Radiology (2014) 43, 20130374. doi: 10.1259/dmfr.20130374

Cite this article as: Nascimento MCC, Nejaim Y, de Almeida SM, Bóscolo FN, Haiter-Neto F, Sobrinho LC, et al. Influence of cone beam CT enhancement filters on diagnosis ability of longitudinal root fractures. *Dentomaxillofac Radiol* 2014; 43: 20130374.

Keywords: cone beam computed tomography; radiographic image enhancement; root fractures

Introduction

The detection of longitudinal root fracture with no displacement of fragments is one of the major challenges in clinical dentistry. Definitive diagnosis is difficult because its clinical symptoms and radiographic

signs are unspecific. In addition, the prognosis is poor and dental extraction is imminent when the fracture is not diagnosed at an early stage.¹⁻³ Incomplete longitudinal root fractures or those with no separation of fragments are difficult to identify on periapical radiographs. The superimposition of adjacent tissues may obscure the visibility of the fracture line.⁴ Because of the limitations

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Received 12 October 2013; revised 11 December 2013; accepted 7 January 2014

of radiographic techniques in detecting non-dislocating longitudinal root fractures, cone beam CT (CBCT) is one option of dental imaging modality that can facilitate the detection of fractures in these conditions. The tooth can be visualized in different views without superimposition of the structures. In addition, the images can be analysed with specific tools to improve image quality. These enhancement tools could facilitate diagnosis.⁵⁻⁹

Filters are tools that use mathematical algorithms to reduce or enhance specific characteristics of the image.⁵ Different studies have analysed the effects of enhancement radiographic digital images to detect longitudinal root fractures and occlusal and proximal caries lesions.⁹⁻¹³ Other studies have evaluated the effect of different digital image filters on various relevant anatomical structures.^{14,15} Some other studies have evaluated effects of sharpen filters on CBCT images to detect transverse root fractures and external root resorption.^{16,17} However up to now, there is a lack of studies on the influence of these enhancement filters on diagnosis ability of longitudinal root fractures. Thus, the aim of this study was to evaluate the effect of different image filters on the detection of non-displacing longitudinal root fractures in CBCT images.

Methods and materials

This research protocol was reviewed and approved by the research ethics committee. 40 extracted human maxillary and mandibular molar teeth inspected under a stereomicroscope at a $\times 10$ magnification (Leica EZ4; Leica Microsystems, Wetzlar, Germany) to confirm the absence of cracks and/or root fracture were selected for the study. The access cavities were performed with spherical diamond burs (Dentsply Maillefer, Ballaigues, Switzerland) and refined with Endo Z bur (Dentsply Maillefer). The root canal was prepared using K3™ rotary system (SybronEndo, Orange, CA) until an apical size of 0.25 mm was achieved. Longitudinal root fractures were induced in 20 teeth using an Instron universal testing machine (Instron Company, Canton, MA). Briefly, a conical metal tip was placed inside the canal, and fractures were induced using controlled pressure applied by the machine. The fractures were characterized as having no separation of the fragments by extending to the outside of the root surface. Each tooth was coated with a wax layer to simulate adjacent structures and then placed in an empty dry human mandible socket. The mandible was coated with three layers of dental wax to simulate soft tissue.¹⁸

Image acquisition was performed using Classic i-CAT CBCT (Imaging Sciences International, Inc., Hatfield, PA), operating at 120 kVp and 8 mA, an exposure time of 26.9 s, a field of view of 8 cm and a voxel size of 0.2 mm. All images were analysed without filter application and with the use of the following filters for XoranCAT™ software v. 3.1.62 (Xoran Technologies®, Ann Arbor, MI): Sharpen Mild, Sharpen Super Mild,

S9, Sharpen, Sharpen 3×3 , Angio Sharpen Medium 5×5 , Angio Sharpen High 5×5 and Shadow 3×3 (Figure 1).

Under dim-light conditions, images were evaluated blindly by three previously calibrated oral radiologists with at least 1 year of experience on the Classic i-CAT CBCT device. Previous calibration consisted of the existence of root fracture in 10 tomograms that did not belong to the study sample. Oral radiologists performed a dynamic evaluation using all slices and the zoom tool. At a 15-day interval, the same observation was repeated. Results at the two time periods were evaluated using kappa statistics to check intra- and interobserver reproducibility.

The sensitivity (correctly identifying the presence of fractures), specificity (correctly identifying the absence of fractures), accuracy (proportion of correctness), positive predictive value (probability of true-positive result occurring) and negative predictive value (probability of false-negative result occurring) were calculated for each filter using SAS® v. 9.1 software (SAS Institute Inc., Cary, NC). The McNemar test was used to evaluate the agreement between all images *vs* the gold standard (p1) and the original images *vs* images with filters (p2); a $p < 0.05$ was considered statistically significant.

Results

Means of intra- and interobserver agreement ranged from good to excellent. Interobserver values ranged from 0.81 to 0.83. Intraobserver agreement was excellent for Sharpen Mild (0.81) and S9 (0.80) values, while it was good for the others: No filter (0.79), Sharpen Super Mild (0.74), Sharpen (0.55), Sharpen 3×3 (0.68), Angio Sharpen Medium 5×5 (0.55) and Angio Sharpen High 5×5 (0.70).

Sensitivity, specificity, positive predictive and negative predictive values and accuracy are presented in Table 1. The highest sensitivity value was obtained using the Angio Sharpen High 5×5 filter. The highest specificity value was given by Angio Sharpen Medium 5×5 filter, whereas the Angio Sharpen Medium 5×5 filter obtained the highest positive predictive value. Negative predictive value was the highest for the S9 filter. There were no statistically significant differences between all images and the gold standard (p1) and between the filtered images and images without filters (p2) ($p > 0.05$).

Discussion

The present study compared the application of eight different enhancement filters in CBCT images to evaluate non-displacing longitudinal root fractures. Previous studies have assessed the effect of filters on the visibility of caries lesions in digital radiographs. These studies showed any effects on diagnostic accuracy by using the

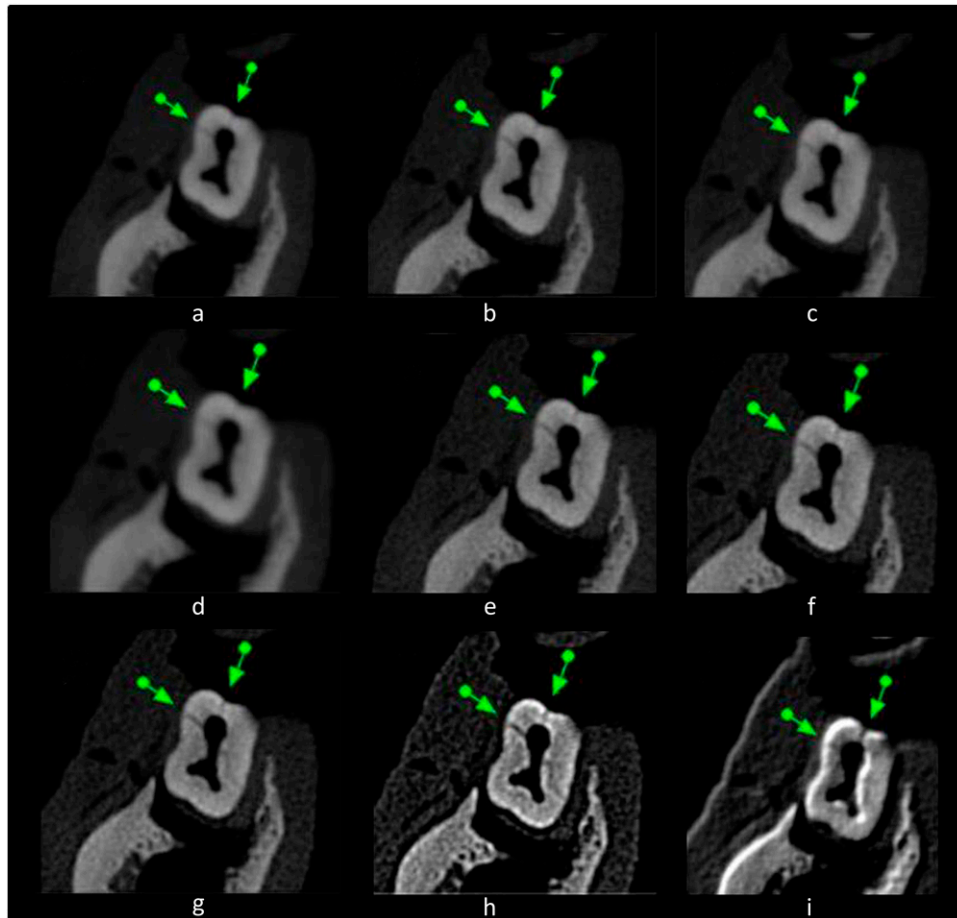


Figure 1 Axial cone beam CT slices show the longitudinal root fracture (indicated by arrows) in first mandibular molar with (a) no filter, (b) Sharpen Mild, (c) Sharpen Super Mild, (d) S9, (e) Sharpen, (f) Sharpen 3 × 3, (g) Angio Sharpen Medium 5 × 5, (h) Angio Sharpen High 5 × 5 and (i) Shadow 3 × 3.

tested filters.^{10,11,19} Another study concluded that some filters have improved the detection of caries lesions, whereas others cannot be recommended.²⁰ However, to the best of the authors' knowledge, this is the first attempt to evaluate the effect of different image filters on the detection of non-displacing longitudinal root fractures in CBCCT images. The results of this study implied that these enhancement filters could not improve significantly the diagnosis of this specific kind of fracture.

A study of the influence of enhancement filters in the diagnosis of transversal root fracture in CBCCT images has compared the accuracy of filtered images with that of original images.¹⁷ The researchers concluded that the Angio Sharpen filter showed better performance than the Sharpen filter and original images. By contrast, in the present study, not only did the Angio Sharpen filters (Angio Sharpen Medium 5 × 5 and Angio Sharpen High 5 × 5) show better results than original images but also

Table 1 Diagnostic test and *p*-value according to different filters

Filters	Sensitivity	Specificity	PPV	NPV	Accuracy	<i>p</i> 1	<i>p</i> 2
No filter	56.8% (9)	58.3% (9)	62.5% (9)	52.5% (9)	57.5% (9)	0.60	–
Sharpen Mild	72.2% (5)	68.2% (7)	65.0% (8)	75.0% (5)	70.0% (6)	0.54	0.13
Sharpen Super Mild	68.3% (7)	69.2% (6)	70.0% (4)	67.5% (6)	68.8% (7)	1.0	0.7
S9	78.8% (2)	70.2% (4)	65.0% (7)	82.5% (1)	73.8% (3)	0.19	0.07
Sharpen	76.3% (3)	73.8% (3)	72.5% (3)	77.5% (3)	75.0% (2)	0.82	0.32
Sharpen 3 × 3	73.0% (4)	69.8% (5)	67.5% (5)	75.0% (4)	71.3% (5)	0.67	0.29
Angio Sharpen Medium 5 × 5	69.6% (6)	76.5% (1)	80.0% (1)	65.0% (7)	72.5% (4)	0.28	0.85
Angio Sharpen High 5 × 5	78.9% (1)	76.2% (2)	75.0% (2)	80.0% (2)	77.5% (1)	0.81	0.32
Shadow 3 × 3	65.9% (8)	66.7% (8)	67.5% (6)	65.0% (8)	66.3% (8)	1.0	0.68

NPV, negative predictive values; *p*1, values of all images vs gold standard; *p*2, values of images with filters vs images with no filters; PPV, positive predictive value.

Values in parentheses relate to filters: from 1 (highest percentage value) to 9 (lowest percentage value).

the Sharpen filters (Sharpen and Sharpen 3×3). This difference can be explained because longitudinal root fractures are presumably more difficult to detect than transverse fractures.²¹

In a previous study, longitudinal root fractures were evaluated in periapical radiographs using four types of digital image filters, such as sharpness, zoom-in, reverse-contrast and pseudo-3D function filters; no differences were found among them.¹² Another study showed that the accuracy of original digital images was better than that of the reverse-contrast and colorized digital image filters in longitudinal root fractures.¹³ One possible explanation for these contradictions may be that the effectiveness of the filters varies depending on the type of filter being used.^{11,15} Instead of contributing to the visualization of fractures, certain enhancement filters have masked the ability to visualize by increasing the digital image noise, whereas others have not improved the diagnosis.²²

A recent study comparing high-resolution and standard zoom imaging modes in CBCT for the detection of longitudinal root fracture showed no significant differences among the diagnostic values of the two image modes used in the diagnosis of root fracture or in the presence of root canal restorations.²³ In this study, no statistically significant differences were observed in the use of filters in images of longitudinal fractures in CBCT.

By comparing similar filters to those used in the present study, a recent study assessed the effect of different enhancement filters (Angio Sharpen Low 3×3 , Angio Sharpen Medium 5×5 , Angio Sharpen High 5×5 , S9, Shadow, Sharpen, Sharpen 3×3 , Sharpen Mild, Sharpen Super Mild, Smooth and Smooth 3×3) on CBCT images when diagnosing simulated external root resorption. The best results were obtained with the Sharpen 3×3 filter (not statistically significant), and the worst statistically significant result was obtained with the Shadow filter.¹⁶ By contrast, the results of accuracy in the present study were higher for Angio Sharpen High 5×5 (0.77)

and Sharpen (0.75) filters (neither statistically significant). Furthermore, neither filter jeopardized the diagnosis. In both studies, the use of filters that theoretically were to improve the diagnosis were not efficient.

The fractures evaluated in the present study were made in molars with no separation of the fragments. According to a previous study, longitudinal root fractures tend to occur more frequently in molars, which have several roots that superimpose on other roots.²¹ It is plausible that fractures with this condition are not detectable by dental radiography. Another methodological aspect that needs to be addressed is the limitation of an *in vitro* study in which only the imaging test is evaluated without considering clinical parameters, such as pulp vitality, history of trauma and pain, which can help in the diagnosis of root fracture.

Overall, the results of this study revealed that it may be difficult to detect longitudinal root fractures. These findings can be explained by the type of fracture performed. There were fractures that simulated an early stage, before soft-tissue proliferation between the root segments separates them.²¹ By contrast, the root canals of the present study were not filled, which may have helped detection. According to a previous study, the presence of radio-opaque materials, such as gutta-percha or artificial crowns, can create artifacts and make interpretation of the image more difficult.³ Future studies should evaluate filled root canals combined with new tools in CBCT software. Due to the great variety of tools commercially available that can handle images, it is necessary to test whether these are useful for diagnostic imaging.

Within the results of the present study, it can be concluded that, although no statistical differences were observed in the diagnosis of root fractures when using filters, these filters seem to improve diagnostic capacity for longitudinal root fractures. Further *in vitro* studies with endodontic-treated teeth and research *in vivo* should be considered.

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