Dentomaxillofacial Radiology (2015) 44, 20140352

birpublications.org/dmfr

RESEARCH ARTICLE

Influence of CBCT enhancement filters on diagnosis of vertical root fractures: a simulation study in endodontically treated teeth with and without intracanal posts

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Objectives: To evaluate the influence of CBCT enhancement filters on the diagnosis of vertical root fractures (VRFs) in teeth with and without metal posts.
Methods: The crowns of 40 uniradicular human teeth were removed and all roots were prepared. 20 teeth were randomly selected, and VRFs were induced using a universal testing machine. The i-CAT (Imaging Sciences International, Hatfield, PA) CBCT was used to scan teeth with and without intracanal metal posts using the following parameters: 0.2 voxel size, 8×8-cm scan size and acquisition time of 26.9 s. Images were evaluated by three observers with and without the use of the following filters: S9, smooth, smooth 3×3, sharpen, sharpen-mild and sharpen 3×3.
Results: Intra- and interobserver agreement ranged from poor to moderate. Images with and without CBCT filters did not show significant differences regarding the area under the receiver operating characteristic curve, as well as sensitivity ($p > 0.05$). As for accuracy, the sharpen-mild filter was superior to the sharpen ($p = 0.03$), but these filters did not differ from all others. For specificity, S9, smooth and original images were superior to sharpen ($p < 0.01$). Results for teeth without posts differed from those for teeth with metal posts in all cases ($p < 0.05$).
Conclusions: The use of enhancement filters in CBCT images has no influence on the diagnosis of VRFs in teeth with metal posts, and their use is not justified.
Dentomaxillofacial Radiology (2015) **44**, 20140352. doi: 10.1259/dmfr.20140352

Cite this article as: Ferreira LM, Visconti MAPG, Nascimento HA, Dallemolle RR, Ambrosano GM, Freitas DQ. Influence of CBCT enhancement filters on diagnosis of vertical root fractures: a simulation study in endodontically treated teeth with and without intracanal posts. *Dentomaxillofac Radiol* 2015; **44**: 20140352.

Keywords: cone beam computed tomography; radiographic image enhancement; vertical root fracture

Introduction

The condition referred to as vertical root fracture (VRF) is a fracture that extends longitudinally from the root apex to the tooth's crown, according to the American Association of Endodontists.[1] The aetiology of VRFs is mainly iatrogenic, usually owing to excessive canal shaping, excessive pressure during gutta-percha compaction or excessive pressure during post-placement.[2] In non-endodontically treated teeth, high occlusal forces following biting on hard objects and/or malocclusions are the main cause of VRFs.[1,3,4]

On radiographic images, the fracture can be seen as a radiolucent line between the fragments along with

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This work was supported by grants-in-aid from CAPES, Brazil.
Received 11 October 2014; revised 19 December 2014; accepted 6 January 2015

a discontinuity of the periodontal ligament shadow.[5] Generally, the clinical symptoms and radiographs are not pathognomonic, which makes the diagnosis of this condition a challenge. Furthermore, periapical radiography provides a two-dimensional representation of three-dimensional anatomical structures; thus, the tooth and the surrounding structures may mask the fracture, particularly if the beam does not pass along the fracture line.[5–9]

CBCT has been used for proper diagnosis of root fractures to overcome the inherent disadvantages of anatomic superimposition.[10] CBCT has allowed dental practitioners to visualize teeth three-dimensionally and with high spatial resolution.[11] While recent studies have demonstrated the superiority of CBCT in detecting root fractures,[1,3,4,6,12–15] there are some limitations to proper imaging when high-density materials such as gutta-percha and intracanal metal posts are present. These materials may create artefacts that impair the quality of CBCT images. Beam hardening and streak artefacts can be superimposed on the root, creating difficulties for image assessment and may even mimic root fractures.[4,6,7,9,12,15–17]

Some specific tools can be used to analyse CBCT images, including filters that use mathematical algorithms to minimize image noise and improve image quality.[18,19] Some studies have shown that CBCT filters improve the diagnosis of root fractures in non-endodontically treated teeth,[5,19] but studies evaluating the influence of filters on the diagnosis of fractures in endodontically treated roots are still missing.

Considering the void in the literature regarding the influence of CBCT enhancement filters on the diagnosis of VRF with the presence of artefacts, our experiments investigated whether CBCT filters improve the diagnostic accuracy of VRFs in teeth with and without metal posts.

Methods and materials

After the study was reviewed and approved without restrictions from the research ethics committee of the Piracicaba Dental School, State University of Campinas, São Paulo, Brazil, (protocol no. 025/2013), 40 uniradicular extracted human teeth were collected and subjected to clinical and radiographic inspection as described elsewhere.[20] Teeth with endodontic treatment, internal or external root resorption, supernumerary roots, obliterated canals, pulpal calcifications and roots with open apices were not used in the study, as well as teeth with cracks and root fractures diagnosed by transillumination. After such selection, the remaining teeth underwent scrapping and root planning for elimination of dental calculus. Subsequently, the crowns were sectioned at the cementoenamel junction limit using a metallographic cutter (ISOMET® 1000 Precision Saw; Buehler, Lake Bluff, IL).

All roots were prepared with a rotary NiTi MTwo® system (VDW, Munich, Germany) with 350 rotations per minute at 1 N under copious irrigation with distilled water. The entire lengths of the root canals were prepared with files following the sequence sizes: size 30, 0.05 taper; size 35, 0.04 taper; size 40, 0.04 taper and size 45, 0.07 taper. Preparations for post placement were made with a low-speed bur (No. 3-Reforpost; Angelus, Londrina, Brazil), creating a space of two-thirds of the total canal length for further adaptation of custom-made intracanal metal posts.

Teeth were divided in two groups of 20 teeth each, namely the control group (without root fracture) and the root fracture group. Fractures were induced with a universal testing machine INSTRON 4411 (Instron Corporation, Canton, MA). A tapered metal tip was placed at the entrance of the root canal and programmed to push into the canal at a speed of 1 mm min^{-1} and stop automatically when the fracture was created. The presence of a VRF was confirmed by visual inspection and transillumination, thereby determining the reference standard for the study. Roots with loss of dentin between fragments were excluded from the study.

To simulate tooth implantation, the prepared roots were covered with wax and placed randomly in the alveolus of the right and left premolars of one dry mandible. The alveolus was enlarged with a cylindrical drill (KG Sorensen, São Paulo, Brazil) to best accommodate the prepared roots.

Prior to scanning, the mounted dry mandible was placed in polystyrene boxes filled with water to simulate soft-tissue attenuation and scattering. Then, each box was scanned with the i-CAT next generation (Imaging Sciences International, Hatfield, PA) for image acquisition. Sagittal, coronal and axial orientation lines were positioned at the central portion of the mandible. Images were acquired with the following parameters: 0.2 voxel size, 8×8-cm scan size, and acquisition time of 26.9 s. All roots were scanned once with and once without their custom-made metal posts. Posts were not cemented to avoid unwanted enlargement of the fracture gap.

Three previously trained independent observers evaluated the images in a room with ideal lighting conditions. The observers were oral radiology specialists experienced in CBCT imaging who had at least two years' experience with the XoranCat® software v. 1.3.62 (Xoran Technologies, Ann Arbor, MI). All images were analysed without filter (original images) and with the following filters: S9, smooth, smooth 3×3, sharpen, sharpen-mild and sharpen 3×3. Figure 1 shows an example of CBCT slices with and without filters. Zooming, as well as brightness and contrast settings, were left to each observer's discretion.

Instructions were given so observers could rate the presence or absence of a root fracture according to a five-point scale (1, definitely absent; 2, probably absent; 3, uncertain; 4, probably present and 5, definitely present). Observers were also asked to indicate which orientation was the most suitable for fracture identification (axial, coronal, sagittal or oblique). Observers evaluated only 20 teeth (5 images) in each session to avoid visual fatigue. A second evaluation was performed under the same

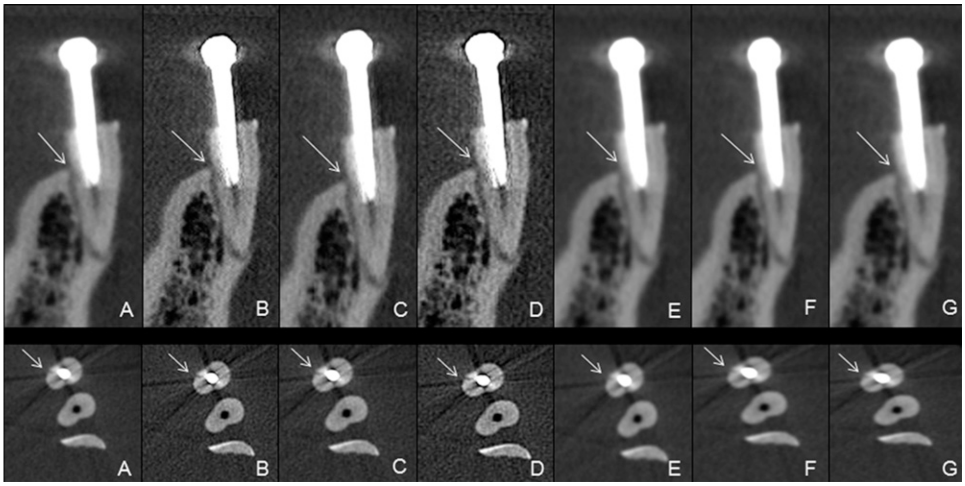

Figure 1 CBCT slices with (a) no filter, and (b) sharpen, (c) sharpen-mild, (d) sharpen 3 × 3, (e) S9, (f) smooth and (g) smooth 3 × 3 filters. Arrows indicate roots with fractures.

conditions with 20% of the sample and after a 30-day interval to assess the reproducibility of the method.

For statistical analysis, the comparison of the evaluations against the reference standard was performed using the receiver operating characteristic curve; the diagnostic values (sensitivity, specificity and accuracy) were also calculated. These analyses were performed in http://www.rad.jhmi.edu/jeng/javarad/roc/JROCFITi.html. For the calculation of sensitivity, specificity and accuracy, rating 3 was used as the cut-off point. These values were calculated for each observer for each image modality (image with and without filters) and each different intracanal condition (with and without post). For statistical analysis of possible differences between these parametric values, two-way ANOVA (filters and intracanal condition) was performed, using a randomized block design, with the evaluators treated as blocks. *Post hoc* comparisons were performed with the Tukey test. The intra- and interobserver reproducibility were evaluated using the weighted kappa test and interpreted based on Landis and Koch.[21] These analyses were performed using SAS software (SAS System Release 9.2 TS Level 2M0; SAS software, Cary, NC). Significance level was set to 5%.

Results

Concerning the diagnosis of VRF, means for intra- and interobserver agreement ranged from poor to moderate. Values are shown in Table 1.

Table 1 Kappa values (95% confidence intervals) for intra- and interobserver agreement

Observer	*1*	*2*	*3*
1	0.41 (0.24–0.59)	0.20 (0.06–0.34)	0.23 (0.07–0.39)
2		0.15 (0.03–0.27)	0.17 (0.02–0.32)
3			0.18 (0.04–0.32)

Average values for the areas under the receiver operating characteristic curve, accuracy, sensitivity and specificity are presented in Table 2. No observer answered Score 3. The areas under the receiver operating characteristic curve and sensitivity showed no differences between the original and filtered images. As for accuracy, the sharpen-mild filter seemed superior to the sharpen, but these filters did not differ from all others. For specificity, the original images, along with filters S9 and smooth, presented higher values than did sharpen, but they did not differ from the others. In all cases, results for teeth without posts differed from those for teeth with metal posts.

Regarding the most suitable orientation for fracture visualization, the observers indicated that sagittal [38%; 95% confidence intervals (CI): 32.7–43.3], axial (33.9%; 95% CI: 28.6–39.1) and coronal (27.5%, 95% CI: 22.5–32.4) slices seemed far more suitable than did oblique (0.6%; 95% CI: 0.04–1.14) slices.

Discussion

In the present study, the diagnosis of VRF was compromised by the presence of intracanal posts. Several studies have confirmed the superiority of CBCT over periapical radiographs for detection of root and endodontic conditions,[6,7,14,15,22] but other studies demonstrated that gutta-percha and metal posts produce artefacts that make visualization of fracture lines in endodontically treated and restored teeth a challenging task.[4,6,7,9,14,16] The beam-hardening effect, for instance, causes the edges of metallic objects to appear brighter than their centres and produces hyperdense streak-like artefacts that can impair diagnostic performance.[6,7,9,15,16]

We tested whether CBCT filters could be an option to decrease the influence of the artefacts on the diagnosis of VRF. It appears that the application of enhancement filters in digital radiography makes diagnosis of

Table 2 Mean values (standard deviation) (95% confidence intervals) of area under receiver operating characteristic (ROC) curve and diagnostic values

Variables	*Intracanal condition*	*Filters*							*Tukey*
		Original images	*Sharpen*	*Sharpen mild*	*Sharpen 3 × 3*	*S9*	*Smooth*	*Smooth 3 × 3*	
ROC	NP	0.70 (0.05) (0.66–0.75)	0.61 (0.1) (0.52–0.71)	0.77 (0.06) (0.71–0.84)	0.68 (0.11) (0.57–0.79)	0.73 (0.11) (0.62–0.84)	0.74 (0.07) (0.67–0.82)	0.71 (0.11) (0.60–0.82)	a
	P	0.54 (0.12) (0.42–0.67)	0.52 (0.11) (0.41–0.64)	0.57 (0.18) (0.40–0.75)	0.60 (0.1) (0.51–0.70)	0.52 (0.08) (0.44–0.61)	0.55 (0.14) (0.42–0.69)	0.54 (0.08) (0.47–0.62)	b
$p = 0.59$	Tukey	A	A	A	A	A	A	A	$p < 0.01$
Acur	NP	0.67 (0.09) (0.59–0.76)	0.51 (0.09) (0.43–0.60)	0.69 (0.05) (0.64–0.73)	0.65 (0.1) (0.54–0.76)	0.66 (0.16) (0.50–0.82)	0.67 (0.06) (0.61–0.74)	0.64 (0.1) (0.53–0.76)	a
	P	0.53 (0.06) (0.48–0.60)	0.47 (0.06) (0.41–0.54)	0.59 (0.13) (0.45–0.72)	0.55 (0.1) (0.44–0.66)	0.55 (0.04) (0.51–0.59)	0.50 (0.04) (0.46–0.54)	0.54 (0.08) (0.48–0.64)	b
$p = 0.03$	Tukey	AB	B	A	AB	AB	AB	AB	$p < 0.01$
Sens	NP	0.50 (0.08) (0.42–0.58)	0.48 (0.15) (0.33–0.62)	0.75 (0.1) (0.65–0.85)	0.60 (0.16) (0.44–0.76)	0.55 (0.13) (0.42–0.68)	0.48 (0.17) (0.31–0.64)	0.64 (0.11) (0.53–0.75)	a
	P	0.20 (0.08) (0.12–0.28)	0.32 (0.2) (0.12–0.53)	0.28 (0.2) (0.07–0.48)	0.45 (0.17) (0.28–0.62)	0.13 (0.1) (0.03–0.22)	0.18 (0.1) (0.08–0.27)	0.20 (0.21) (0.01–0.41)	b
$p = 0.08$	Tukey	A	A	A	A	A	A	A	$p < 0.01$
Spec	NP	0.85 (0.1) (0.75–0.95)	0.58 (0.25) (0.33–0.82)	0.63 (0.1) (0.53–0.72)	0.70 (0.14) (0.56–0.84)	0.78 (0.26) (0.52–1.03)	0.88 (0.19) (0.69–1.06)	0.70 (0.24) (0.46–0.94)	a
	P	0.87 (0.19) (0.69–1.06)	0.62 (0.23) (0.39–0.86)	0.90 (0.08) (0.82–0.98)	0.65 (0.23) (0.42–0.88)	0.98 (0.05) (0.93–1.02)	0.80 (0.14) (0.66–0.94)	0.93 (0.1) (0.83–1.02)	b
$p < 0.01$		A	B	AB	AB	A	A	AB	$p = 0.03$

Acur, accuracy; NP, no post; P, with post; Sens, sensitivity; Spec, specificity.
Means followed by different letters (upper case in rows—filters and lower case in columns—post) differ from each other ($p \leq 0.05$).

caries[23,24] and VRFs[5,8] more accurate. However, others have concluded that the diagnosis of occlusal caries and root fractures is not improved by the application of filters.[23,25] As one may conclude, the influence of filters on aiding dental diagnosis is still controversial; furthermore, most studies about the diagnostic advantages of filters used periapical radiographs, and the few studies that evaluated the application of CBCT filters for diagnosis of root fractures did not include teeth with intracanal materials.[5,19] The importance of this study is that it is the first to evaluate the influence of CBCT filters on diagnosis of VRF in endodontically treated teeth with and without metal posts.

The results of this study indicate that these filters do not improve significantly the diagnosis of VRF. These results differ from those of Wenzel et al[5] who assessed the influence of CBCT filters (Angio sharpen and sharpen) in the diagnosis of root fractures and concluded that the Angio sharpen filter improved diagnostic sensitivity. However, CBCT parameters and the type of fracture were different from those used in the present study; moreover, the teeth used in their work did not have intracanal materials, which may explain the differences in the results. In a recent study with CBCT filters for aiding the diagnosis of VRFs, the authors believed that filter application somehow improved the diagnostic capability; yet, significant differences between the original and filtered images were not observed.[19] Again, endodontically treated teeth were not included in the above-cited study, which makes the results of the present study and theirs difficult to compare.

One option in trying to decrease the effect of artefacts in CBCT images compromised by the presence of high-density materials is applying the metal reduction algorithm available in some equipment. Apparently, this algorithm improves image quality, as evaluated objectively when phantoms are scanned;[26,27] however, its use has a negative effect on the accuracy of root fracture detection.[28]

Our findings regarding intra- and interobserver agreement showed levels ranging from poor to moderate; the sensitivity was also low. One must bear in mind, however, that diagnosis of VRFs is a major challenge in clinical practice,[22] especially in the presence of intracanal metal posts.[6,7,9,15,16] This may serve as an explanation for the low levels of agreement and sensitivity found in this study and in others using CBCT images in the presence of high-density materials.[6,9,16] As the specificities were generally greater than sensitivities, it appears that most observers selected "not present" when artefacts made the evaluation difficult. The fact that Score 3 (uncertain) had not been used as a response by the observers should be highlighted. This facilitated the calculation of sensitivity, specificity and accuracy, as Score 3 could make their impossible, because it is not appropriate to *a posteriori* assign it to present or absent. We believe that this could be attributed to the training that the observers received before evaluations, when they were instructed that Score 3 should be reserved to images that were impossible to evaluate.

The three-dimensional CBCT images appear to offer a valuable method for assessing root canal systems.[9,16]

However, it is important to remember that the currently available dental CBCT systems offer resolutions far lower (by approximately one order of magnitude) than those of modern intraoral radiography. Another important limitation to a wider use of CBCT in endodontics is that the systems are incapable of reducing the field of view to the level of a single tooth and thus expose the patient to excessive radiation. Therefore, according to the SEDENTEXCT guidelines[29] and the European Society of Endodontology position statement,[30] CBCT is indicated only if both clinical and conventional radiographic data do not provide adequate information for the final diagnosis of root fracture. Moreover, the presence of intracanal materials that can produce artefacts must be taken into account.

In many cases, the diagnosis of root fractures is aided by other clinical findings such as pain, swelling, dental mobility and the presence of an isolated deep periodontal pocket.[12] These conditions are not amenable to simulation, constituting a limitation of *in vitro* studies. In addition, our results are related to the i-CAT scanner and its software; further studies with other scanners and software should be considered.

Conclusion

The use of enhancement filters in CBCT images has no influence on the diagnosis of VRFs in teeth with metal posts. Owing to this, their use is not justifiable.

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