Dental Traumatology

Dental Traumatology 2013; **29**: 41–46; doi: 10.1111/j.1600-9657.2012.01126.x

Detection of vertical root fractures by conventional radiographic examination and cone beam computed tomography – an *in vitro* analysis

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Key words: vertical root fracture; cone beam computed tomography; conventional radiograph

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Accepted February 3, 2012

Abstract – *Objectives:* This study compared the ability of conventional radiographic and cone beam computed tomography (CBCT) examinations to detect vertical root fractures (VRF) in teeth with or without root canal treatment and metallic posts. Furthermore, the influence of using different voxel sizes from CBCT images was assessed. *Methodology:* Sixty single-rooted human teeth were randomly divided into two groups: experimental and control. Twenty teeth were endodontically prepared and obturated with gutta-percha, twenty had a metallic postcemented after the filling, and twenty had no preparation. The teeth from the experimental group were fractured. All teeth were radiographed with three different horizontal angles, and after, CBCT images were acquired following three protocols in which the variation was the voxel resolution (0.4, 0.3, and 0.2 mm). Three calibrated examiners assessed the images. *Results:* Chi-squared test showed no statistical difference among the images in detecting VRFs. The results of the diagnostic performance tests presented similar ability to detect VRFs when conventional radiographic examination was compared with 0.2 and 0.3-voxel CBCTs scans, in roots without endodontic treatment and metallic post. Moreover, specificity, sensitivity, and accuracy findings were similar for both 0.2 and 0.3-voxel resolution scans for teeth that are not root filled. However, it was observed that in teeth with root canal treatment and a post, the accuracy was higher when 0.2-mm voxel resolution was used. *Conclusion:* The radiographic examination with horizontal angle variation should be encouraged as the first complementary approach to assess the presence of VRFs. If conventional imaging is not capable to provide adequate information, CBCT can be indicated if a root fracture is strongly suspected. The root condition should then guide the voxel resolution choice, selecting 0.3-voxel for not root filled teeth and 0.2-voxel for teeth with filling and/or a post.

The diagnosis of vertical root fractures (VRFs) in teeth that have endodontic treatment is a challenge for dental professionals. One of the main reasons for the difficult diagnosis of VRFs is the fact that the final diagnosis is based on a panel of several signs and symptoms rather than a pathognomonic one (1–3). The most common clinical findings associated with VRFs are deep osseous defects and the presence of a sinus tract located closer to the gingival margin (3, 4).

In an extensive literature review, Tsesis et al. (5) pointed out that there is a lack of evidence-based data concerning the diagnostic accuracy and effectiveness of clinical and conventional radiographic dental evaluation for the diagnosis of VRF in endodontically treated teeth. However, diagnostic information directly influences clinical decisions (6). VRFs are responsible for 32.1% of the reasons for extraction of endodontically treated teeth in a 5-year follow-up study (7). Therefore, the early detection of VRFs is important to achieve a good prognosis for future treatment, preventing additional bone loss and resorption of the surrounding tissues (8) and leading to a more predictable outcome (6).

Imaging is an important diagnostic adjunct to the clinical assessment of VRF. Conventional radiography systems fail to provide detailed information regarding teeth and adjacent structures because of projection artifacts such as magnification, distortion and superimposition (9). A VRF can be overlooked if the x-ray beam does not pass along the fracture line and two or more radiographs with a 4–15-degree variation are recommended (10, 11). The cone beam computed tomography (CBCT) was introduced in Endodontics to assess specific characteristics of the alveolar bone and apical pathologies (true size, extent, nature and position), resorptive lesions, complex root canal anatomy and also root fractures (12). The dose of radiation is lower than medical tomography and depends on the voxel resolution and the time of exposure. Small voxel size requires a high number of sections during examination, increasing the patient's radiation exposure (13, 14). The information provided by CBCT involved a three dimensional image, without overlapping structures, favoring a more precise definition of the problem and treatment planning, especially for VRFs (6, 9, 15).

Despite the advantages provided by the CBCT technology, there are some limitations. The presence of streaking artifacts can compromise the quality of the scan (16). In Endodontics, specific materials such as gutta-percha and intracanal metallic post may contribute to artifacts formation (17–19), decreasing the observer's confidence in diagnosis VRFs (20). CBCT is not found currently in every dental office (6), and conventional radiograph remains the first adjunctive image examination that is available to the clinician. Therefore, the aim of this study was to compare the ability of the conventional radiographic examination and CBCT, with different voxel sizes, to detect VRFs in teeth presenting or not root canal treatment and metallic posts.

Material and methods

This study was approved by the Ethics Committee in Research from the Federal University of Rio Grande do Sul (UFRGS, Porto Alegre, Rio Grande do Sul, Brazil). Sixty extracted single-rooted human teeth, inspected under magnification to confirm the absence of cracks and/or root fracture, were selected for the study. The samples were sectioned at the cement–enamel junction. To prepare the specimens and simulate a clinical situation, each root was covered by a thin layer of wax, simulating the periodontal ligament resiliency, and then placed in an acrylic resin block. This precaution ensured that the fractured teeth had no split nor were the fragments largely separated.

The samples were randomly divided into two groups: experimental (A, C, and E) and control (B, D, and F), with 10 samples in each subgroup. The subgroups A and B were prepared for endodontic treatment and subsequently obturated with gutta-percha; the subgroups C and D, after the endodontic treatment, had the obturation material removed from the coronal and middle thirds of the canals and a metallic postcemented; the subgroups E and F had no preparation. The teeth of experimental group had a tapered chisel inserted in the canal space and gently tapped with a hammer to induce a vertical root fracture. The samples were visually inspected under magnification to detect the absence or presence of VRF, representing the gold standard.

All teeth were radiographed (Dental Intraoral D-Speed Film; size 2; 0.4 s, Kodak, Rochester, NY, USA) with three different horizontal angles, based on the buccal surface: orthogonal (0°), mesial, and distal angulation (15°) (11). The film images were evaluated under transmitted light from a radiographic view box under magnification. Ambient light from the viewer was removed by masking.

For the tomographic acquisition, all samples were put together and placed on the desk of the i-CAT tomography device (120 kVp, 3-8 mA; Imaging Sciences International, Inc, Hatfield, PA, USA). Axial, frontal, and sagittal sections were obtained with specific protocols based on the voxel resolution: 0.4-mm voxel [8-cm field of view (FOV), 20 s for acquisition], 0.3-mm voxel (8-cm FOV, 20 s for acquisition), and 0.2-mm voxel (8-cm FOV, 40 s for acquisition). Images were analyzed using the i-CAT Vision software (Imaging Sciences International Inc, Hatfield, PA, USA).

Images were analyzed by three blinded, previously calibrated examiners. The previous calibration consisted of the identification of the existence of VRF in 10 radiographs and tomograms that did not belong to the study sample. 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 inter-observer reproducibility, compared with the gold standard. The values obtained for Kappa were >0.70.

Diagnostic ability for both conventional radiographic method and tomographic method (considering voxel resolution) was measured by specificity, sensitivity, and accuracy findings. Sensitivity relates to the test's ability to identify positive results. Therefore, it detects the ratio between the number of true positives and the sum between true positives and true negatives. The sensitivity of a test is the proportion of samples that have VRFs that test positive for it. Specificity relates to the ability of the test to identify negative results. The specificity of a test is defined as the proportion of samples that do not have VRFs that will test negative for it. Hence, it is the ratio between the number of true negatives and the sum between true negative and false positive outcomes. The accuracy is the proportion of true results (both true positives and true negatives) in a test group. The mean values for specificity, sensitivity, and accuracy among the three examiners were used. To verify the accuracy of each exam independent of the root condition, the area under the ROC curve was calculated: it is a plot of the true positive rate against the false positive rate of a diagnostic test. The mode among the examiners' diagnosis was determined. The Kappa index was employed to check the agreement between the mode and the gold standard in each subgroup, and the chi-squared test was used to verify whether there were any differences among the four groups. Statistical analysis was carried out by the software SPSS v.19.0 for Windows (SPSS, Chicago, IL, USA).

Results

The radiographic images of a tooth with VRF are shown in Fig. 1, and the tomographic scans with different voxel resolution are shown in Fig. 2.

The mean values for sensitivity, specificity, and accuracy for each voxel size (0.4, 0.3, 0.2 mm) and conventional radiograph in each group are shown in Table 1. When used the 0.2-mm voxel, sensitivity, specificity and accuracy were higher than the other groups. The sensitivity values decreased for higher voxel sizes. However, the specificity values were constant,

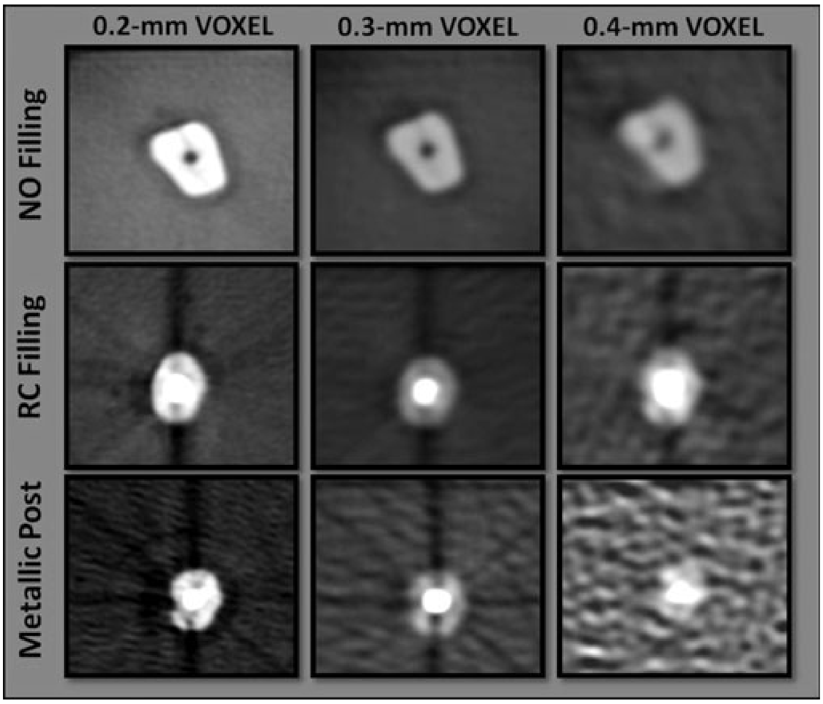

Fig. 1. Radiographic examination of the specimens with experimentally induced vertical root fractures and different root conditions: not root filled, gutta-percha, and metallic post. Depending on the horizontal angle variation, the fracture line can, or cannot, be seen.

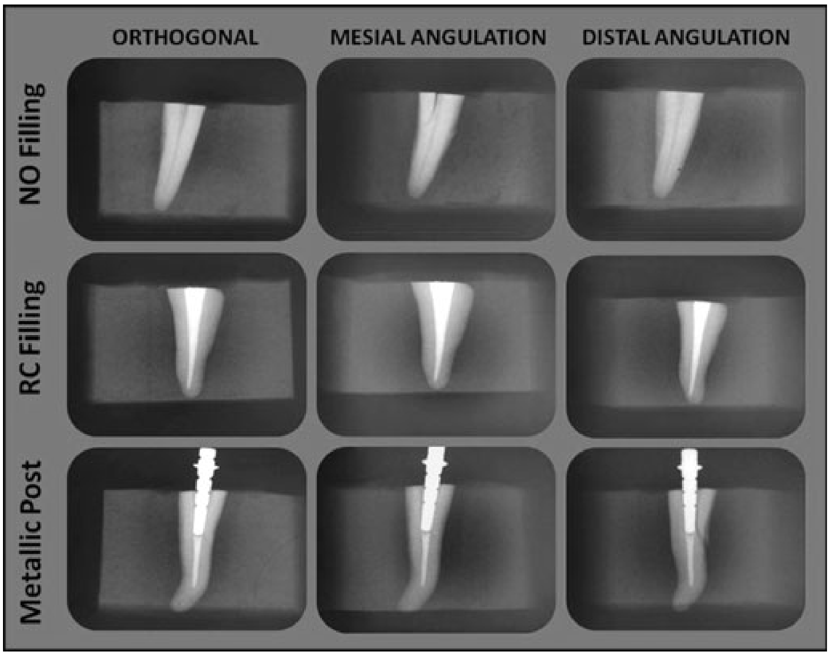

Fig. 2. Axial tomographic cross-sections of the same specimen of Fig. 1 with experimentally induced vertical root fractures and different root conditions: not root filled, gutta-percha, and metallic post. Depending on the voxel size and the root canal status, the fracture line can, or cannot, be seen.

except for the 0.4-mm voxel images. The area under ROC curve was higher for 0.2-mm voxel resolution as well. Chi-squared test showed no statistical significance among the groups.

The Kappa values for the agreement between the observer's mode and the gold standard are shown in Table 2. A reduction in the Kappa value was observed with increasing voxel size. The radiographic conventional examination showed values similar to the 0.3-mm voxel images, except for teeth that had the metallic intracanal post. A significant reduction in the Kappa value was observed when the 0.2- and 0.3-mm voxel

Table 1. Mean values of sensitivity, specificity, and accuracy for each group, regarding the diagnostic method, ROC curve for each group, and significance of the chi-Squared Test (*P* value)

	Cone beam computed tomography											
	0.2-mm voxel			0.3-mm voxel			0.4-mm voxel			Conventional radiographic		
	No RC filling	RC Filling	Metallic post	No RC filling	RC Filling	Metallic post	No RC filling	RC Filling	Metallic post	No RC filling	RC Filling	Metallic post
Sensitivity	0.97	0.97	0.83	0.87	0.67	0.63	0.76	0.60	0.57	0.93	0.63	0.47
Specificity	1.00	0.93	0.80	0.97	0.74	0.91	0.80	0.70	0.59	0.83	0.83	0.97
Accuracy	0.98	0.95	0.82	0.92	0.70	0.68	0.77	0.65	0.57	0.88	0.88	0.72
ROC Curve[1]	0.967			0.867			0.683			0.800		
χ^2 test	P = 0.075											

[1]Area under ROC Curve.

Table 2. Kappa values for the consensus vs the gold standard

	Cone beam computed tomography			
	0.2-mm voxel	0.3-mm voxel	0.4-mm voxel	Radiographic evaluation
No RC filling	1.00	0.90	0.60	0.90
RC filling	1.00	0.50	0.40	0.50
Metallic post	0.80	0.80	0.10	0.40

images were compared in endodontically treated roots. High Kappa values in the detection of VRFs were observed for the 0.2- and 0.3-mm voxel groups, especially in teeth presenting metallic intracanal post (Kappa = 0.80). There was a reduction in the Kappa values for the results provided by the radiographic and 0.4-mm voxel images, respectively.

Discussion

It is known that CBCT provides more accurate imaging information about the diagnosis of endodontic diseases and conditions, but there is little evidence on the influence of the root canal filling or the presence of a metallic post in the detection of VRFs. In this study, the conventional radiographic approach with horizontal angle variation and the CBCT with different voxel sizes allowed comparisons to be made of the diagnosis of VRFs in roots presenting the above-mentioned conditions.

Cone beam computed tomography seems to improve the diagnostic ability of VRFs because it allows visualizing the object from multiple angles as well as allows using very thin slices without disturbance of overlapping of structures (13, 21). Liedke et al. (22) and Mello et al. (17) reported that using different voxel sizes during examination results in different diagnostic abilities for simulated external root resorption cavities and VRFs, respectively. The dose of radiation should always be considered when an imaging exam is requested, and it is known that the voxel size is directly linked to patient's exposure to radiation (13, 23). Even though the CBCT tends to be adopted as the 3D imaging choice in the next years, the conventional radiograph examination is the most frequent adjunct diagnostic tool that is available in the dental office.

Even though the chi-squared test showed no statistical significance among the groups, the results of the diagnostic tests, especially the values of the area under the ROC curve, allow significant considerations regarding the different kinds of images acquisitions. The results of the diagnostic test for conventional radiographic exam showed similar ability to detect VRFs when compared with 0.2- and 0.3-voxel CBCTs scans in roots without endodontic treatment and metallic post. The results were different from the previously reported by Mora et al. (24) and Hassan et al. (20). The increase in the conventional radiograph's sensitivity and specificity in our study is probably associated with the use of 3 different horizontal angulations, as suggested earlier (11). The presence of root canal filling and metallic post promoted a reduction in the conventional radiograph sensitivity and no alteration in the specificity. Mora et al. (24) pointed out that the absence of soft tissues and the surrounding alveolar/cortical bone is a critical factor that might be considered and it should influence the results. However, the findings of this study support the concept that the conventional radiograph examination associated with horizontal angular variation can be an important tool to detect VRFs, especially in teeth without endodontic treatment and metallic posts.

The overall specificity, sensitivity and accuracy findings for the VRFs detection were high and similar for both 0.2- and 0.3-voxel resolution scans for teeth that are not root filled. However, the 0.2-voxel scans seemed to be the best diagnostic approach when the root canal has a filling or the metallic post. The image quality is directly affected by the protocol for achieving the image in the CBCT examination, especially the voxel size (25). At the same time, the 0.3-mm voxel resolution scans need a short time for image acquisition, which reduces patient exposure to x-rays (13, 23). Although Melo et al. (17) suggested that the 0.2-mm should be used to detect VRFs independent of the root canal condition, the results from this study support the utilization of 0.3-mm voxel resolution to investigate the presence of VRFs in teeth that are not root filled.

Previous studies reported a decrease in the CBCT specificity when the root canal filling was present because it produces streaking artifacts (20, 25). In this study, the root canal filling and the metallic post exerted a higher influence over the specificity of CBCT than over its sensitivity. The high specificity could be explained by the fact that, once radiopaque materials create streaking artifacts that mimic fracture lines, and the examiner knows that most teeth were scored negatively for VRF.

In this study, the 0.2-mm voxel resolution allowed a high detection of VRF, regardless the root canal condition, as demonstrated by the area under the ROC curve. However, for teeth that are not root filled both 0.2- and 0.3-mm voxel resolutions had similar results for the tested parameters, so this last one should be the preferred resolution for detecting VRFs, because the radiation dose is lower than 0.2-mm voxel scans.

According to ALARA principle, it is important to select diagnostic methods that employ low radiation doses to obtain a precise diagnosis, depending on the clinical condition. The radiographic evaluation should be the first imaging resource to assess the presence of VRFs, because of its wide availability, low cost, and relatively lower radiation exposure for the patient. The horizontal angle variation must be a complementary approach if the suspected VRF was not detected in the orthogonal radiographic examination. If both clinical and the conventional radiographic data were not able to provide adequate information, CBCT can be indicated as the imaging method to assess the presence of VRFs and the CBCT protocol adopted will depend on the root condition, selecting 0.3-voxel for not root filled teeth and 0.2-voxel for teeth with filling or filling and a post. Recently, CBCT with restrict FOV has been used to analyze specific areas of the oral cavity, contributing to reduce the presence of artifacts and the patient exposure to radiation (26, 27). The tomography employed in this study did not allow to obtain images with restrict FOV. Therefore, further studies should be conducted using restrict FOV associated with lower voxel-sized images to evaluate their diagnostic ability and also to determine the effective radiation dose.

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