RESEARCH

The influence of metallic posts in the detection of vertical root fractures using different imaging examinations

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Objectives: To assess the influence of metallic posts in the detection of simulated vertical root fractures (VRFs) using the following imaging examinations: 2 cone beam CT (CBCT) systems [CBCT1: NewTom[®] 3G (QR Srl, Verona, Italy) and CBCT2: i-CAT Next Generation[®] (Imaging Sciences International, Hatfield, PA)] and film and digital radiographs. Additionally, the influence of the orientation of the fracture line in the detection of VRFs was evaluated.

Methods: 100, human, single-rooted endodontically treated premolars were divided into 5 groups (Group 1: with posts and buccolingual VRFs, Group 2: with posts and mesiodistal VRFs, Group 3: without posts and with buccolingual VRFs, Group 4: without posts and with mesiodistal VRFs, and Group 5: with posts and without VRFs). The premolars were placed in human mandibles and imaged using the four examination modalities. The sensitivity and the specificity of each examination in the experimental groups were calculated. The data were analysed using Student's *t*-test.

Results: The presence of metallic posts reduced the sensitivity of the CBCT1 system ($p = 0.0244$). Digital radiographs and the CBCT1 and CBCT2 systems had a higher sensitivity in detecting buccolingual fractures in teeth with posts, whereas film and digital radiographs had a higher sensitivity in detecting buccolingual fractures in teeth without posts ($p < 0.05$). The CBCT1 examination demonstrated the lowest specificity ($p < 0.05$).

Conclusions: The presence of metallic posts did not influence the sensitivity of most of the examinations, excluding the CBCT1 system. The fracture line orientation may influence VRF detection.

Dentomaxillofacial Radiology (2014) **43**, 20130287. doi: 10.1259/dmfr.20130287

Cite this article as: Jakobson SJM, Westphalen VPD, Silva Neto UX, Fariniuk LF, Schroeder AGD, Carneiro E. The influence of metallic posts in the detection of vertical root fractures using different imaging examinations. *Dentomaxillofac Radiol* 2014; **43**: 20130287.

Keywords: vertical root fractures; cone beam computed tomography; radiographs; digital radiographs; metallic post

Introduction

Vertical root fractures (VRFs) represent approximately 2–5% of all dental fractures¹ and are present in 10–20% of extracted teeth that are endodontically treated.² VRFs occur mostly in older patients.³

These fractures have a multifactorial aetiology and are associated with dental trauma, parafunctional

habits, excessive occlusal forces, diseases or clinical procedures that cause an accentuated loss of tooth structure, or an exaggerated force during the condensation procedure of endodontic filling or when placing intracanal posts.^{1,4–6} VRFs occur in vital and non-vital teeth; however, endodontically treated premolars and molars and teeth with intracanal posts are most frequently affected.^{1,2,4} Fractures may be incomplete or complete according to their extension and occur in the

buccolingual or mesiodistal direction, but most frequently in the buccolingual direction.^{1,7}

An early diagnosis is essential to ensure that adequate treatment can be performed quickly. In certain types of fractures, therapeutic measures may be adopted to preserve the involved tooth.^{8–10} In cases in which extraction is indicated, performing the extraction early on will result in less additional damage to adjacent bone structures because of the development of an inflammatory and infectious condition, which would make it difficult to treat the affected area.^{1,10}

VRFs present variable and unspecific clinical and radiographical signs and symptoms. During the initial stages of a VRF, these signs are similar to those of endodontic, periodontal and combined endoperiodontal complications, which may hinder a diagnosis.^{1,5}

Film and digital periapical radiographs are the most frequent imaging examinations that are performed in endodontic practice. In cases of VRFs, the images reveal different aspects that vary from an aspect of normality to different patterns of radiolucent lesions. These changes may occur in the periapical region, laterally in the mesial or distal direction or may involve both sides of the affected root in the shape of a halo that surrounds the periapical region and extends laterally; however, the involvement of both sides of the root is the most prevalent aspect in the more advanced stages of VRFs.^{11,12} However, the fracture line may rarely be observed in radiographs unless the plane of the fracture is parallel to the radiation beam with no superimposition of radiopaque filling materials.¹³ Confirmation of the fracture occasionally requires exploratory surgery; however, it may be difficult to observe cases of incomplete fractures that involve only the lingual wall during the surgical procedure.^{1,12}

Diagnostic failures result in the indication of inappropriate procedures and unnecessary expenses for the patient, which can strain the professional/patient relationship and subject the professional to legal complications.¹⁴

Recent studies have demonstrated the effectiveness of cone beam CT (CBCT) in the diagnosis of root fractures.^{15–26} However, imaging artefacts owing to the presence of radiopaque materials in the area of interest are a limitation of this technology.^{13,17,19,20} Endodontically treated teeth with posts are most susceptible to VRFs;^{1,2,4} therefore, it is necessary to investigate the reliability of CBCT images in these cases.

The main objective of this study was to assess the influence of metallic posts in endodontically treated teeth and the influence of the orientation of the fracture line (buccolingual or mesiodistal) in the detection of VRFs using two CBCT systems and film and digital radiographs.

Methods and materials

For this study, a total of 100 human, single-rooted premolars were selected. The teeth were radiographed to observe the root canal anatomy. The integrity of the root

was confirmed using a light microscope M900 at $\times 10$ magnification (DF Vasconcellos, Londrina, Brazil). Teeth with root caries, fillings, pulp calcifications, root resorptions, cracks or root fractures were excluded. The teeth were decontaminated with 10% buffered formol solution and rinsed in a saline solution. The coronal portion was removed at the cement–enamel junction using low-speed stainless steel disks with a diamond coating (DHpro; Paranaguá, Paraná, Brazil), and the root canals were prepared using rotary ProTaper® (Dentsply Maillefer, Rio de Janeiro, Brazil) instruments up to size F3. The root canal filling was performed with F3 gutta-percha cones (Dentsply Maillefer) using the single-cone technique and AH Plus® sealer (Dentsply DeTrey, Konstanz, Germany).

In 60 teeth, the post space preparation was performed using Gates-Glidden burs No. 2 (Dentsply Maillefer) and Largo burs No. 2 (Dentsply Maillefer) to remove the coronal two-thirds of the root canal obturation. Pre-fabricated metallic posts (Reforpost II; Angelus, Londrina, Brazil) were placed with zinc phosphate cement (SS White, Rio de Janeiro, Brazil).

Simulations of incomplete VRFs were performed in 80 teeth: 40 teeth in the buccolingual direction and 40 teeth in the mesiodistal direction. Fractures were performed along two-thirds of the root, extending in depth close to the root canal without exceeding it, using diamond-coated steel discs that were 22 mm in diameter and 0.20 mm thick (DHpro) and a straight handpiece at low speed. This procedure was adapted from Kondylidou-Sidira *et al.*²⁷

The teeth were numbered and randomly divided into the following 5 groups of 20 specimens each: Group 1 included posts and buccolingual VRFs, Group 2 included posts and mesiodistal VRFs, Group 3 did not include posts but included buccolingual VRFs, Group 4 did not include posts but included mesiodistal VRFs, and Group 5 included posts but did not include VRFs. Overall, 10 sets of 10 teeth were randomly selected and placed in the premolar, canine and left and right incisor sockets in dry human mandibles. The mandibles were covered with bovine muscle that was cut into strips approximately 1.5 mm thick and placed in the vestibular and lingual directions to simulate soft tissue.²⁸ The teeth were submitted to the following four types of imaging examinations: CBCT1 (NewTom® 3G; QR Srl, Verona, Italy), CBCT2 (i-CAT Next Generation®; Imaging Sciences International, Hatfield, PA) and film and digital radiographs. The CBCT examinations were performed according to the following protocols: CBCT1 [110 kVp; 0.3 mA; voxel: 0.2 mm; field of view (FOV): 6°; 0.5 mm thick cuts and a distance of 0.5 mm between the cuts] and CBCT2 (120 kVp; 5 mA; voxel: 0.2 mm; FOV: 16 cm in diameter $\times$ 8 cm high; 0.5 mm thick cuts and a distance of 0.5 mm between the cuts).

With the teeth in the same position, film and digital periapical radiographs were taken in an orthoradial, mesioradial and distoradial aspect using film positioners (Indusbelo, Londrina, Brazil) (Figure 1). To obtain

Figure 1 (a) Orthoradial radiography. (b) Distobuccal radiography in which the arrow shows the vertical root fracture (VRF). (c) Mesiodistal radiography. (d) Cone beam CT 2 (CBCT2) axial view. (e) CBCT1 axial view in which the arrow shows artefacts that are associated with a metallic post, which mimic a VRF in a tooth without a VRF. (f) CBCT2 axial view in which the arrows show the presence of metallic artefacts that are associated with metallic posts. (g, h) CBCT1 sagittal views in which the arrows show VRFs. (i) A CBCT2 sagittal view shows a VRF. (j, k) CBCT1 cross-sectional views show artefacts that are associated with metallic posts.

mesioradial and distobuccal radiographs, the horizontal angle was modified by 15° to the long axis of the teeth. The images were acquired using the Kodak 2200 (Eastman Kodak Company, Rochester, NY) appliance (60 kVp, 7 mA, an exposure time of 0.198 s for film radiographs and 0.1 s for digital radiographs). The film radiographs were taken using E-Speed Film size no. 2 (Eastman Kodak Company), and processing of the radiographs was performed in the A/T 2000[®] XR automatic processing unit (Air Techniques Inc., Marietta, Georgia). The film radiographs were mounted in black frames and shown on a light box in a room with reduced lighting. The digital radiographs were obtained using a sensor plate in the Digora[®] Phosphor Plate System (Soredex, Tuusula, Finland), which measured 35×45 mm and had an active area of 30×40 mm and a specification of 416×560 pixels. After exposure, the sensors were read by the Digora System, and the images were analysed on an AOC Deevo 19" L19W31 monitor (AOC; Manaus, Amazonas, Brazil), which had an effective resolution of 1366×768 pixels and a 6-bit depth. No software tools were used to manipulate the images.

The analysis of all of the images was performed in a blind experiment by two specialists experienced in dental radiology, which included two sessions at an interval of 2

weeks for each imaging examination. The reading order of the examinations was film, digital radiographs, the CBCT1 and the CBCT2 systems. Both examiners received training during a calibration session, and the criteria for detecting the VRFs were clearly defined. The presence of a VRF was recorded for each image. An index of 0 was adopted for the absence of a fracture, whereas an index of 1 indicated the presence of a fracture. When a fracture was observed in at least one of the three angles on the radiographs, the presence of a fracture was considered.

In the analysis of the images that were generated by the CBCT systems, the images were presented in three planes (axial, sagittal and coronal), and the presence of a fracture was considered when the fracture line was observed in at least two different planes at the selected slice location. The sequence of the observation of the images and the use of imaging software tools was optional. A 22" LG monitor (W2252TQ; LG Electronics[®], São Paulo, Brazil) with an effective resolution of 1680×1050 pixels and an 8-bit depth was used with Newton NNT software v. 2 (QR Srl) to analyse the images that were generated by the CBCT1 system (NewTom 3G). A 22" LG monitor (W2252TQ; LG Electronics) with an effective resolution of 1680×1050 pixels and an 8-bit depth was used to analyse the images that were generated by the CBCT2 system (i-CAT

Next Generation). The images were analysed by using the Xoran software (XoranCAT® v. 2.0.21; Xoran Technologies, Ann Arbor, MI).

The data were recorded to determine the sensitivity and specificity of each examination in the experimental groups. Overall, the sensitivity for each examination was first calculated for teeth with and without metallic posts. The sensitivity was calculated per fracture orientation. Overall, the specificity was calculated for each examination using the teeth in Group 5. Student's *t*-test was used to determine the significance of the differences between the sensitivity and the specificity of the four types of examinations and between the groups. The level of significance was 5%. The data were analysed using Statistica™ 8.0 software (StatSoft, Tulsa, OK). The Kappa test was used to determine intra- and interobserver agreement.

Results

The kappa value for interobserver agreement was 0.45 for all of the data. Considering the different examinations, these values were 0.264, 0.334, 0.362 and 0.751 for film radiographs, digital radiographs, the CBCT1 and the CBCT2 systems, respectively. The intraobserver agreement for all of the modalities ranged from 0.82 to 0.93 for both observers, which is considered almost perfect agreement.

The sensitivity and the specificity of the examinations in the experimental groups are reported in Table 1. The presence of posts reduced the sensitivity of the CBCT1 system (*p* = 0.0244). The comparison of the examinations revealed that both CBCT systems demonstrated a higher sensitivity than the film and digital radiographs in teeth with and without posts (*p* = 0.000). In the teeth without posts, differences were found between the CBCT1 and CBCT2 systems (*p* = 0.0244).

The CBCT1 system had the lowest specificity. Significant differences were observed between the CBCT1 system and film radiographs (*p* = 0.0170), digital radiographs (*p* = 0.0330) and the CBCT2 system (*p* = 0.0005).

The analysis of the influence of fracture orientation indicated that more buccolingual VRFs were detected in teeth with posts than mesiodistal VRFs using the digital radiographs (*p* = 0.0006) and the CBCT1 and CBCT2 systems (*p* = 0.0236). Additionally, this finding was obtained in teeth without posts using the film and digital radiographs (*p* = 0.000) (Table 2).

Discussion

The advantages of the CBCT system as a complementary resource to conventional radiographical examinations in planning and diagnosis are well established in endodontics, especially in complex clinical situations in which the benefits are greater than the potential risks.^{24–26} Film and digital periapical radiographs have many limitations in the detection of VRFs because of their two-dimensional nature, especially when fractures are mesiodistally oriented. In these situations, CBCT examinations can improve the accuracy of a diagnosis.^{15–26} However, in endodontically treated teeth and in teeth with metallic posts, the presence of image artefacts may influence the interpretation of results, which raises doubts regarding the validity of examining patients using CBCT.^{13,16,18,19} A cost–benefit relationship can be justified only when studies demonstrate that these tests have a high sensitivity and specificity and effectively contribute to a diagnosis.

Image artefacts are visualized structures in reconstructed data, which are not present in the object under investigation. These artefacts are induced by discrepancies between the physical conditions of the CBCT system and the composition, position and behaviour of the object under study and between the simplified mathematical assumptions that are used for three-dimensional reconstruction.²⁹ In teeth with root canal fillings and metallic posts, image artefacts occur because of differences in the attenuation of the radiation beam by high-density materials, which significantly absorb X-rays. This phenomenon results in data loss, a lack of homogeneity and low image resolution. Artefacts are produced because of beam hardening, which results in two types of artefacts: a distortion of metallic structures owing to differential absorption, known as cupping artefacts, and the appearance of streaks and dark bands between two dense objects.²⁶ The presence of these artefacts may lead to false results because they mimic fracture lines and may mask fractures that are present.^{13,15,23,29–34}

Previous studies that assessed VRF detection using different imaging modalities in teeth with endodontic fillings and metallic posts demonstrated the influence of the filling material on the results.^{13,23} The presence of an endodontic filling did not alter the sensitivity of the imaging examinations but significantly reduced the specificity of digital radiographs¹³ and five CBCT systems.²³ Other studies found that the presence of metal posts reduced the sensitivity and specificity of the imaging examinations but did not significantly influence VRF detection by CBCT systems.^{18,35}

Table 1 Overall values of sensitivity and specificity in the experimental groups by the examinations

Examinations	Film radiography	Digital radiography	CBCT1	CBCT2
Sensitivity Groups 1 and 2 (with posts)	62.5%	55%	93.75%	96.25%
Sensitivity Groups 3 and 4 (without posts)	65%	57.5%	100%	93.75%
Specificity Group 5	82.5%	80%	57.5%	92.5%

CBCT, cone beam CT.

Table 2 Influence of the direction of fracture orientation on the overall sensitivity of the examinations

Groups	Examinations	Film radiology	Digital radiology	CBCT1	CBCT2
1—Posts buccolingual VRF	Sensitivity	65%	75%	100%	100%
2—Posts mesiodistal VRF	Sensitivity	60%	35%	87.5%	87.5%
	<i>p</i> -value <i>t</i> -test ^a	0.645	0.0006	0.0236	0.0236
3—Without posts buccolingual VRF	Sensitivity	90%	87.5%	100%	95%
4—Without posts mesiodistal VRF	Sensitivity	40%	27.5%	100%	92.5%
	<i>p</i> -value <i>t</i> -test ^a	0.000	0.000	1	0.5579

CBCT, cone beam CT; VRF, vertical root fracture.

^aStudents' *t*-test for difference between two proportions.

In this investigation, to reproduce a clinical situation, the root canals were filled with gutta-percha and AH Plus sealer and metallic posts were cemented. Artefacts were observed in the images that were generated by the CBCT systems (Figure 1), and the presence of metallic posts influenced the sensitivity of the CBCT1 system. By contrast, both CBCT systems exhibited a high sensitivity in teeth with and without posts with values >90%. When these results were compared with those of the film and digital radiographs, there were significant differences, which is in agreement with previous *in vitro*^{13,16–19,22} and *in vivo* studies.^{15,20} By contrast, other studies^{30,35} reported no differences in VRFs detection between film and digital radiographs and a CBCT system, which can be explained by the different methodologies that were used by the authors.

Different research methodologies have been used in studies to induce VRFs, including the use of universal testing machines^{17,30,34} or a mechanical force, such as inserting a chisel into the canal space and tapping the chisel with a hammer.^{8,13,23,35} The resulting VRFs were indistinctly buccolingual or mesiodistal. An objective of this study was to assess the influence of fracture line orientation on the detection of VRFs; therefore, VRFs were simulated using discs, and the fractures were parallel to the axis of the tooth. Clinically, VRFs may occur obliquely to the axis of the tooth, which may be a limitation of this study.

The thickness of VRFs has rarely been evaluated in *in vitro* tests; however, Ozer¹⁶ compared the accuracy of digital radiography with that of a CBCT system in the detection of 0.2 and 0.4 mm VRFs and found that wider fractures were diagnosed with greater accuracy using both examinations, but CBCT was significantly more accurate. A recent study³⁴ demonstrated that the cracks in five extracted teeth varied in size from 30 to 100 µm. Based on these values, the authors induced incomplete VRFs and assessed the accuracy of periapical radiography and a CBCT system in detecting the presence of VRFs that varied in size from 50 to 100 µm. The results indicated that both methods were not accurate in the detection of VRFs. In this study, incomplete VRFs with a thickness of 0.2 mm were simulated. This simulation may not reflect *in vivo* conditions, especially in the early stages of VRFs, and may have interfered with the results. However, no single technique in the current literature for the induction or simulation of VRFs can

reproduce a clinical condition in which fractures would have variable characteristics, including differences in extension, thickness or the location along the dental root.

The group of teeth with posts and without fractures was included in the analysis to determine the specificity of the imaging examinations. There were no significant differences between the film and digital radiographs and the CBCT2 system. However, the CBCT1 system had the lowest specificity. Significant differences were observed when the CBCT1 system was compared with the other examinations. Considering the specificity of the CBCT systems, false-positive results were obtained in 42.5% and 7.5% of the images from the CBCT1 and CBCT2 systems, respectively. This finding may be explained by the differences in the quality of the images that were generated by the CBCT systems. The detector design technology in the CBCT2 system included a flat panel detector, whereas the CBCT1 system used an image intensifier tube/charged-coupled device, which is inferior owing to its reduced dynamic range, contrast and spatial resolution and increased pixel noise and image artefacts.^{23,30} Additionally, the FOV for both the CBCT systems varied. The smallest FOV in the CBCT2 system should have enhanced the detection of VRFs.³⁵

In this study, film and digital radiographs were taken from three different horizontal angulations to reduce the limitations of a bi-dimensional representation, which may have increased the sensitivity and specificity of the examinations.^{21,36} Similarly, a 0.2 mm voxel resolution was adopted in the CBCT systems to improve the detection of the fractures, as suggested by previous investigations.^{18,36}

To test whether the orientation of the VRFs may have influenced their detection, this study used the same number of buccolingual and mesiodistal VRFs. The mesiodistal VRFs are difficult to detect using the film and digital radiographs.^{13,30} The overall sensitivity values that were obtained for the film and digital radiographs ranged from 55% to 62.5%. These findings suggest that intraoral radiographs should be acquired in three different horizontal angulations in cases of suspected VRFs and when a diagnosis remains questionable, a CBCT scan examination should be indicated.

In this study, more buccolingual VRFs were detected in teeth with posts than mesiodistal fractures using digital radiographs and CBCT1 and CBCT2 systems. In

addition, this finding was obtained in teeth without posts using film and digital radiographs. A higher number of buccolingual fractures was expected to be detected using radiographs because of previous results.^{13,30} This result may be owing to the difficulty in positioning the parallel beam of radiation to the fracture line in mesiodistal fractures. However, the detection of VRFs using the CBCT systems was influenced by the orientation of the fractures, which was unexpected because these systems allow for a three-dimensional observation of the areas under study.^{23–26} In addition, previous studies reported a higher sensitivity for a CBCT system in detecting buccolingual or obliquely oriented VRFs than mesiodistal VRFs; however, this difference in sensitivity was not significant.^{13,30} One possible explanation is that the main direction of the artefacts owing to beam hardening is in the mesiodistal direction. This occurs because the beam has to traverse many teeth and roots in that direction, which induces beam hardening, because hydroxylapatite is a massive filtering substance. The presence of metallic posts may have increased the artefacts and made it harder to detect the VRFs in the mesiodistal direction.

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Conclusion

The presence of metallic posts did not influence the sensitivity of most of the examinations in the detection of VRFs in endodontically treated teeth, excluding the CBCT1 system.

The sensitivity of the examinations was higher in the detection of buccolingual VRFs in teeth with posts than mesiodistal VRFs using digital radiographs and the CBCT1 and CBCT2 systems. Additionally, this finding was obtained in teeth without posts using film and digital radiographs.

The CBCT systems demonstrated a higher sensitivity than the film and digital radiographs in detecting VRFs in endodontically treated teeth with and without posts; however, the accuracy depended on the type of CBCT system that was used.

The CBCT systems are useful tools in the detection of VRFs; however, they may present false results. Therefore, a diagnosis of VRFs should be based on the sum of the data that are obtained from anamnesis, clinical and imaging examinations.

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