

Comparison of Five Cone Beam Computed Tomography Systems for the Detection of Vertical Root Fractures

Bassam Hassan, BDS, MSc,^{*‡} Maria Elissavet Metska, DDS, MSc,^{‡#} Ahmet Rifat Ozok, DDS, PhD,[†] Paul van der Stelt, DDS, PhD,^{*} and Paul Rudolf Wesselink, DDS, PhD[†]

Abstract

Introduction: This study compared the accuracy of cone beam computed tomography (CBCT) scans made by five different systems in detecting vertical root fractures (VRFs). It also assessed the influence of the presence of root canal filling (RCF), CBCT slice orientation selection, and the type of tooth (premolar/molar) on detection accuracy. **Methods:** Eighty endodontically prepared teeth were divided into four groups and placed in dry mandibles. The teeth in groups Fr-F and Fr-NF were artificially fractured; those in groups control-F and control-NF were not. Groups Fr-F and control-F were root filled. CBCT scans were made using five different commercial CBCT systems. Two observers evaluated images in axial, coronal, and sagittal reconstruction planes. **Results:** There was a significant difference in detection accuracy among the five systems ($p = 0.00001$). The presence of RCF did not influence sensitivity ($p = 0.16$), but it reduced specificity ($p = 0.003$). Axial slices were significantly more accurate than sagittal and coronal slices ($p = 0.0001$) in detecting VRF in all systems. Significantly more VRFs were detected among molars than premolars ($p = 0.0001$). **Conclusions:** RCF presence reduced specificity in all systems ($p = 0.003$) but did not influence accuracy ($p = 0.79$) except in one system ($p = 0.012$). Axial slices were the most accurate in detecting VRFs ($p = 0.0001$). (*J Endod* 2010;36:126–129)

Key Words

Cone beam computed tomography scan, diagnosis, root canal filling, vertical root fracture

From the Departments of *Oral and Maxillofacial Radiology and †Cariology Endodontology Pedodontlogy, Academic Centre for Dentistry Amsterdam, Amsterdam, The Netherlands

[‡]Bassam Hassan and Maria Elissavet Metska contributed equally to this manuscript.

Address requests for reprints to Dr Ahmet Rifat Ozok, Department of Cariology Endodontology Pedodontlogy, Academic Centre for Dentistry Amsterdam (ACTA), Louwesweg 1 1066 EA Amsterdam, The Netherlands. E-mail address: r.ozok@acta.nl.

0099-2399/\$0 - see front matter

Copyright © 2010 by the American Association of Endodontists. All rights reserved.
doi:10.1016/j.joen.2009.09.013

The clinical and radiographic diagnosis of vertical root fractures (VRFs) is often complicated. A local deep pocket, dual sinus tracts, and a halo type of lateral radiolucency are among the symptoms (1–8). Often these symptoms are not convincing to justify tooth extraction, which usually is the elected treatment because the prognosis of VRFs is poor. Therefore, the exact diagnosis of a VRF is crucial to avoid erroneous extraction. However, because of the two-dimensional nature of periapical radiographs (PRs) and the inherent superimposition projection artifacts, visualizing a VRF is difficult, especially when the fracture line is mesiodistally oriented (9). The presence of a VRF is only confirmed by direct visualization (10). This may sometimes be accomplished by means of a surgical diagnostic flap, which is quite invasive.

Cone beam computed tomography (CBCT) scans specifically designed for the maxillofacial region have become largely accessible to clinicians and have replaced conventional computed tomography scans for dentomaxillofacial applications because of their reduced radiation dose and installation and maintenance costs (11–13). Prototype flat-panel CBCT systems were found useful in detecting VRFs (14, 15). Those systems, however, cannot be used to scan patients. Recently, a CBCT system was found more accurate than PR in detecting VRFs in root-filled teeth (16). The superiority of CBCT over PR is primarily because of the high contrast and three-dimensional nature of tomographic imaging, which permits direct visualization of fracture lines otherwise masked in PR.

Several dentomaxillofacial CBCT systems are currently on the market. Those systems differ from each other in detector design, patient scanning settings, and data reconstruction parameters (17–21). Several scanning and reconstruction factors including scan field of view (FoV) selection and voxel size, the number of basis projections (acquisitions) used for reconstruction, and image artifacts have significant influence on image quality in CBCT. CBCT systems vary in their image quality and ability to visualize anatomic structures (22–27). This variation is most prominent with small and delicate anatomic structures such as periodontal ligament and trabecular bone (28). It is, therefore, probable that different CBCT systems vary in their ability to detect VRFs because the fractures are small. The influence of the presence of root canal filling (RCF) on VRF visibility could also vary among the different scanners. Additionally, the selection of the reconstruction plane (axial, sagittal, or coronal) used for the detection or the type of tooth could have an influence on VRF detection. This study aimed to compare the accuracy of five clinical CBCT systems for detecting VRFs in endodontically prepared teeth and to assess the influence of the presence of a RCF, slice orientation selection, and the type of tooth on accuracy for detecting VRF in each system.

Material and Methods

Sample Preparation

We used the method described by Hassan et al (16). Briefly, 40 extracted premolars and 40 molars were inspected on a stereomicroscope (Wild Photomakroskop M400; Wild, Heerbrugg, Switzerland) for the absence of VRFs. Endodontically prepared root canals (size F3, ProTaper; Dentsply Maillefer, Tulsa, OK) were divided into two experimental (Fr-F and Fr-NF) and two control groups (control-F and control-NF). Each group consisted of 10 premolars and 10 molars ($n = 20$). The teeth were decoronated to eliminate a bias of enamel fractures.

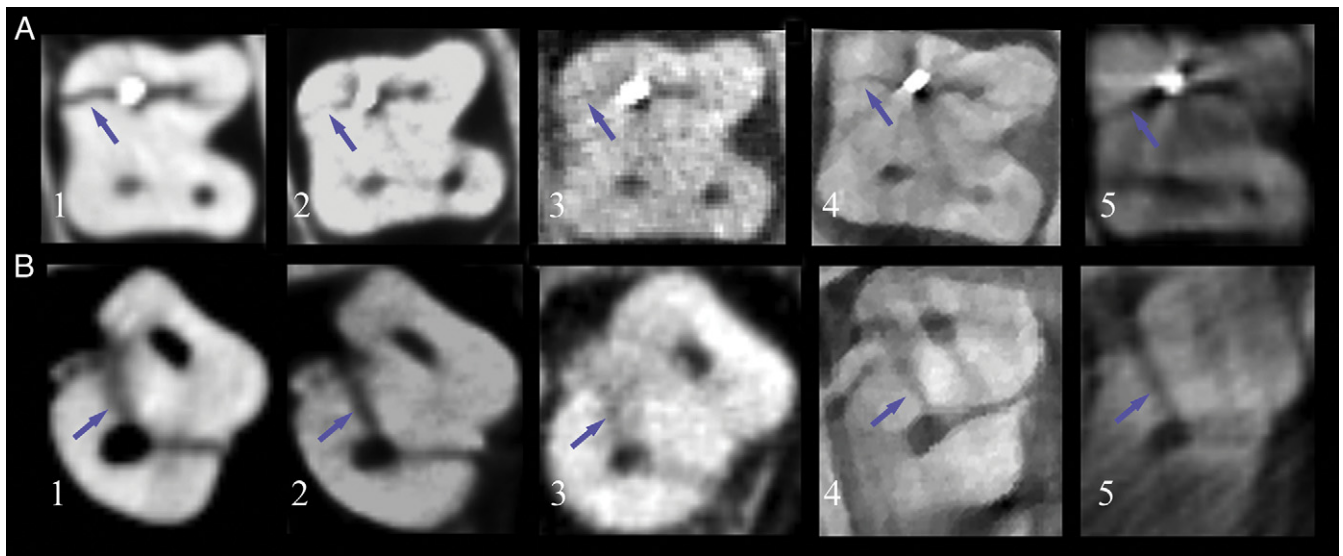


Figure 1. An example of an axial cross-section showing a vertical root fracture line (arrow) in an endodontically filled root (row A) and in a nonfilled root (row B). CBCT systems from left to right: (1) Next Generation i-CAT, (2) Scanora 3D, (3) NewTom 3G, (4) AccuTomo MTC-1, and (5) Galileos 3D.

The roots in groups Fr-F and Fr-NF were vertically fractured using the method described by Hassan et al (16). The fractured teeth in these two groups were inspected again under the stereomicroscope to confirm the presence of VRFs. Fracture line orientation (buccolingual or mesiodistal) was also recorded. A well-fitting gutta-percha cone was inserted in the canals of groups Fr-F and control-F. One investigator, who was not involved in the observation, coded the teeth and fixed them with agar-agar (Merck, Darmstadt, Germany) in premade sockets bilaterally in the posterior region in 10 dry human mandibles, which were coated with three layers of dental wax (Tenatex Red; Kemdent, Swindon, UK) buccally and lingually to provide some level of soft-tissue simulation.

Radiographic Scans

The sample was scanned using five CBCT systems according to the protocols recommended by the manufacturer. The CBCT systems were NewTom 3 G (QR SLR, Verona, Italy), Next Generation I-CAT (Imaging Sciences International, Hatfield, PA), Galileos 3D (Sirona Germany, Bensheim, Germany), Scanora 3D (Soredex, Tuusula, Finland), and 3D AccuTomo-xyz (J. Morita, Kyoto, Japan). System specifications and scan settings are shown in Table 1. The scanned data were exported in DICOM 3 file format.

Data Analysis

The axial, coronal, and sagittal tomographic slices of the datasets were created in Amira image analysis software (V4.2.0; Visage imaging, Carlsbad, CA). Two blinded and calibrated experienced endodontists assessed the images on each slice orientation independently. The calibration included training on the radiographic features of VRF on CBCT scans. The visibility of a radiolucent fracture line crossing the root either completely or partially on at least two consecutive slices was the main radiographic feature for detecting a VRF (16). Images were displayed on a 21-inch flat-screen panel (Philips Brilliance, Best, The Netherlands). Each observer assessed the presence of VRF on a dichotomous scale (fractured/not-fractured). A separate score for detecting VRF was obtained for each slice orientation (axial, sagittal, and coronal). The root was considered fractured when a fracture line was detected on any one of the three slices.

Statistical Analysis

The data were analyzed on SPSS software (v16.0; SPSS Benelux, Gorinchem, The Netherlands). The radiographic measurements were compared with the gold standard (physical observations) using a two-sided chi-square test to determine the sensitivity and specificity of each system in detecting VRFs. A univariate analysis of variance test assessed the influence of the choice of CBCT system, the presence of an RCF, reconstruction slice orientation (axial, coronal, or sagittal), and the effect of tooth type (premolar or molar) on the detection accuracy of VRF. Additionally, the influence of VRF line orientation (buccolingual or mesiodistal) was also assessed. A Cohen kappa measured the overall and per system agreement between the two observers. The alpha value was set to 0.01.

Results

The kappa agreement measure, sensitivity, specificity, and accuracy results for the five CBCT systems are summarized in Table 1. There was a statistically significant difference among the five scanners in their sensitivity for detecting VRF ($p = 0.0001$) and no statistically significant difference in their specificity ($p = 0.17$). There was a statistically significant difference in overall accuracy among the five systems ($p = 0.0001$) (Table 1). The presence of RCF did not influence sensitivity ($p = 0.16$), but it reduced specificity ($p = 0.003$). RCF did not reduce overall accuracy in detecting VRFs on CBCT scans ($p = 0.79$) except for the Galileos 3D system ($p = 0.012$). Axial slices were significantly more accurate than sagittal and coronal slices ($p = 0.0001$) in detecting VRFs in all systems (Table 1). Significantly more VRFs were detected among molars than premolars ($p = 0.0001$). There was no significant influence of VRF line orientation (buccolingual or mesiodistal) on detection accuracy ($p = 0.21$). The overall agreement between the observers was fair ($\kappa = 0.385$). The agreement for the i-CAT was good ($\kappa = 0.68$), and it was better compared with those for other systems (Table 1).

Discussion

The Next Generation i-CAT was the most accurate system, followed by the Scanora 3D. The other three systems were significantly less accurate in detecting VRFs. Possible explanations for the variation include

TABLE 1. Scan and Reconstruction Settings for the Five CBCT Systems

Scanner	Manufacturer-detector type	kVp	mA	Scan FoV (cm)	Voxel size (mm)	Sensitivity overall	Specificity overall	Accuracy overall	Accuracy axial	Accuracy coronal	Accuracy Sagittal	Accuracy RCF	Accuracy Premolars	Accuracy Molars	Kappa
NewTom 3G	AFP imaging-IIT/CCD* Int-PPD†	110	2.4	10 × 10	0.20	30.4	95	62.7	61.5	51.9	55.8	62.5	54.4	71.3	0.25 fair
Next Generation I-CAT	Imaging Sciences Int-PPD†	120	5	10 × 16	0.25	77.5	91.3	84.4	84.4	65.7	68.2	81.3	78.8	90	0.68 good
Galileos 3D	Sirona-IIT-CCD	85	7	15 × 15	0.30	18.8	85	53.8	51.9	53.8	48.8	51.9	47.5	56.3	0.03 poor
Scanora 3D	Soredex-PPD	85	10	7.5 × 10	0.20	57.5	85	71.3	70.7	68.2	63.2	72.5	63.8	78.8	0.42 moderate
AccuTomo-XYZ	J.Morita-IIT/CCD	80	3.3	3 × 4	0.25	48.1	90.7	69.4	67.4	59.9	65.1	66.9	58.9	78.9	0.38 fair

Sensitivity, specificity, overall accuracy for the detecting vertical root fractures, and accuracy for root canal filled (RCF) teeth for tooth type (premolar or molar) per CBCT system. Kappa interobserver agreement per system.

*Image Intensifier Tube/Charged Coupled Device.

†Flat-panel detector.

differences in detector type and characteristics, scan FoV selection, and voxel size (which influence contrast and resolution) as well as system-specific image artifacts.

Based on detector design technology, current CBCT systems are categorized into the following groups: (1) image intensifier tube/charged coupled device (IIT/CCD) combinations or (2) flat-panel detectors (FPDs) (29). It is reported that IIT/CCD detectors are inferior to FPD in terms of reduced dynamic range, contrast and spatial resolution, increased pixel noise, and image artifacts (30, 31). I-CAT and Scanora 3D are both FPD-based systems; the other three systems are IIT/CCD based (Table 1). This might explain the superiority of those two systems to the other three.

The influence of FoV selection during the scan is equally important. Broadly, based on FoV selections, CBCT systems are categorized into the following: (1) small (dental) volume usually used for scanning few teeth or one jaw; (2) medium (maxillofacial) volume covering both jaws, the maxillary sinus, and part of the nose; and (3) large (craniofacial) volume, which covers the entire maxillofacial region extending in some systems to the cranial vertex superiorly (17–21). FoV selection is directly related to voxel size and influences spatial and contrast resolution. Larger FoV selection provides less resolution and contrast in comparison with small FoV, and this directly influences the visibility of anatomic structures with CBCT (28–31). Some CBCT systems, such as Galileos 3D, provide a single-scan FoV selection of 15 × 15 cm, which cannot be modified. Therefore, it was impossible to standardize the FoV and voxel size selections for all of the systems included in this study. However, an attempt was made to obtain the scans with comparable scan FoVs and voxel sizes as much as possible.

The number of basis projections obtained during the scan, data reconstruction parameters (algorithms), and machine-specific image artifacts may also contribute to the variation among the systems (28–33). An image of low quality is difficult to be interpreted, and a definite diagnosis cannot be done easily. More false-positives and/or false-negatives arise, thus reducing the system’s overall accuracy. This is a possible explanation for the fair and poor kappa scores, especially for the Galileos 3D system (Table 1).

The presence of RCF reduced specificity in all systems, leading to more false-positive results (Table 1). Radiopaque materials such as gutta-percha cones create streak artifacts that mimic fracture lines (16). However, the presence of RCF did not reduce overall detection accuracy except in the Galileos system, which was associated with many artifacts (Fig. 1).

VRFs extend by definition longitudinally onto the root surface. Therefore, it is logical that a horizontal cross-section perpendicular to the VRF should provide the best detection. Indeed, axial slices were more accurate than coronal and sagittal ones in detecting VRFs in all systems (Table 1). The fracture line orientation had no significant influence on the detection accuracy. This corroborates a previous finding that CBCT is insensitive to VRF line orientation because of its three-dimensional nature (16).

The study was limited to the CBCT systems that were accessible when this study was conducted. New models with different technical specifications appear on the market each year from the same or other manufacturers. Whether those CBCT systems or models would perform differently remains to be investigated.

In conclusion, there is a large variation among the different CBCT systems in their ability to detect VRFs *ex vivo* possibly because of the detector characteristics of each system, FoV and voxel size selections, and other several CBCT-specific image artifacts. The presence of RCF reduced specificity in all systems, but it did not influence overall accuracy except in the Galileos 3D system. Axial slices are more accurate than sagittal and coronal for detecting VRFs.

Acknowledgment

We would like to thank Dr Hans Verbeij for his support with the statistical analysis and the following individuals and institutes for the CBCT scans: Dr R. Jacobs (Oral Imaging Centre, KULEUVEN University, Leuven, Belgium) for the Scanora 3D and the Accui-Tomo-xyz scans, Drs C. Politis and Sun Yi (Department of Oral and maxillofacial Surgery, St. John's Hospital, Gent, Belgium) for the Galileos 3D scans, and Dr H. De Jonge (Atrium Medical Centre, Heerlen, The Netherlands) for the I-CAT scans.

References

1. Tamse A, Fuss Z, Lustig J, et al. Radiographic features of vertically fractured, endodontically treated maxillary premolars. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1999;88:348–52.
2. Tamse A, Fuss Z, Lustig J, et al. An evaluation of endodontically treated vertically fractured teeth. *J Endod* 1999;25:506–8.
3. Tamse A, Kaffe I, Lustig J, et al. Radiographic features of vertically fractured endodontically treated mesial roots of mandibular molars. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006;101:797–802.
4. Tamse A. Vertical root fractures in endodontically treated teeth: diagnostic. signs and clinical management. *Endod Topics* 2006;13:84–94.
5. Krell KV, Rivera EM. A six year evaluation of cracked teeth diagnosed with reversible pulpitis: treatment and prognosis. *J Endod* 2007;33:1405–7.
6. Opdam NJ, Roeters JJ, Loomans BA, et al. Seven-year clinical evaluation of painful cracked teeth restored with a direct composite restoration. *J Endod* 2008;34:808–11.
7. Shemesh H, van Soest G, Wu M-K, et al. Diagnosis of vertical root fractures with optical coherence tomography. *J Endod* 2008;34:739–42.
8. Pitts DL, Natkin E. Diagnosis and treatment of vertical root fractures. *J Endod* 1983;9:338–46.
9. Rud J, Omnell K. Root fractures due to corrosion. Diagnostic aspects. *Scand J Dent Res* 1970;78:397–403.
10. Moule AJ, Kahler B. Diagnosis and management of teeth with vertical root fractures. *Aust Dent J* 1999;44:75–87.
11. Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008;106:106–14.
12. Cotton TP, Geisler TM, Holden DT, et al. Endodontic applications of cone-beam volumetric tomography. *J Endod* 2007;33:1121–32.
13. Loubele M, Bogaerts R, Van Dijck E, et al. Comparison between effective radiation dose of CBCT and MSCT scanners for dentomaxillofacial applications. *Eur J Radiol* 2009;71:461–8.
14. Mora MA, Mol A, Tyndall DA, et al. In vitro assessment of local computed tomography for the detection of longitudinal tooth fractures. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007;103:825–9.
15. Hannig C, Dullin C, Hülsmann M, et al. Three-dimensional, nondestructive visualization of vertical root fractures using flat panel volume detector computer tomography: an ex vivo in vitro case report. *Int Endod J* 2005;38:904–13.

16. Hassan B, Metska ME, Ozok AR, et al. Detection of vertical root fractures in endodontically treated teeth by cone beam computed tomography. *J Endod* 2009;35:719–22.
17. Mozzo P, Procacci C, Tacconi A, et al. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. *Eur Radiol* 1998;8:1558–64.
18. Kobayashi K, Shimoda S, Nakagawa Y, et al. Accuracy in measurement of distance using limited cone-beam computerized tomography. *Int J Oral Maxillofac Implants* 2004;19:228–31.
19. Araki K, Maki K, Seki K, et al. Characteristics of a newly developed dentomaxillofacial X-ray cone beam CT scanner (CB MercuRay): system configuration and physical properties. *Dentomaxillofac Radiol* 2004;33:51–9.
20. Sukovic P. Cone beam computed tomography in craniofacial imaging. *Orthod Craniofac Res* 2003;6(suppl):131–6. discussion 179–82.
21. Arai Y, Tammissalo E, Iwai K, et al. Development of a compact computed tomographic apparatus for dental use. *Dentomaxillofac Radiol* 1999;28:245–8.
22. Loubele M, Guerrero ME, Jacobs R, Suetens P, et al. A comparison of jaw dimensional and quality assessments of bone characteristics with cone-beam CT, spiral tomography, and multi-slice spiral CT. *Int J Oral Maxillofac Implants* 2007;22:446–54.
23. Loubele M, Maes F, Schutyser F, et al. Assessment of bone segmentation quality of cone-beam CT versus multislice spiral CT: a pilot study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006;102:225–34.
24. Loubele M, Maes F, Jacobs R, et al. Comparative study of image quality for MSCT and CBCT scanners for dentomaxillofacial radiology applications. *Radiat Prot Dosimetry* 2008;129:222–6.
25. Mischkowski RA, Scherer P, Ritter L, et al. Diagnostic quality of multiplanar reformations obtained with a newly developed cone beam device for maxillofacial imaging. *Dentomaxillofac Radiol* 2008;37:1–9.
26. Kwong JC, Palomo JM, Landers MA, et al. Image quality produced by different cone-beam computed tomography settings. *Am J Orthod Dentofacial Orthop* 2008;133:317–27.
27. Bryant JA, Drage NA, Richmond S. Study of the scan uniformity from an i-CAT cone beam computed tomography dental imaging system. *Dentomaxillofac Radiol* 2008;37:365–74.
28. Liang X, Jacobs R, Hassan B, et al. A comparative evaluation of dentomaxillofacial CBCT and MSCT image data—Part I: on subjective image quality. *Eur J Radiol* 2009 Apr 30. [Epub ahead of print].
29. Scarfe WC, Farman AG. What is cone-beam CT and how does it work? *Dent Clin North Am* 2008;52:707–30.
30. Katsumata A, Hirukawa A, Okumura S, et al. Effects of image artifacts on gray-value density in limited-volume cone-beam computerized tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007;104:829–36.
31. Katsumata A, Hirukawa A, Okumura S, et al. Relationship between density variability and imaging volume size in cone-beam computerized tomographic scanning of the maxillofacial region: an in vitro study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009;107:420–5.
32. Mora MA, Mol A, Tyndall DA, et al. Effect of the number of basis images on the detection of longitudinal tooth fractures using local computed tomography. *Dentomaxillofac Radiol* 2007;36:382–6.
33. van Daatselaar AN, van der Stelt PF, Weenen J. Effect of number of projections on image quality of local CT. *Dentomaxillofac Radiol* 2004;33:361–9.