Section 2.2
Comparison of five cone beam computed tomography Systems for the detection of vertical root fractures

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Section 2.2

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 ($p = 0.0001$).
Introduction

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.
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 Photomakroscop 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. 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 Accuitomo-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 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 ($k = 0.385$). The agreement for the i-CAT was good ($k = 0.68$), 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 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 (18).

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.
**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) AccuiTomo MTC-1, and (5) Galileos 3D.
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<tr>
<th>Detector Design</th>
<th>NewTom 3G</th>
<th>Next Generation I-CAT</th>
<th>Galileos 3D</th>
<th>Scanora 3D</th>
<th>AccuTomo - XYZ</th>
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<td>mA</td>
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<td>Field of View (FoV) in cm</td>
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Table 1. Scanning and reconstruction parameters for the five different CBCT systems used. 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 and the Kappa interobserver agreement per CBCT system.

*Image Intensifier Tube/Charged Coupled Device.
*Flat-panel detector.
References


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