Detection of Vertical Root Fractures by Using Cone Beam Computed Tomography with Variable Voxel Sizes in an In Vitro Model

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Abstract

Introduction: The aim of this study was to compare the diagnostic accuracy of cone beam computed tomography (CBCT) scans with different voxel resolutions in the detection of simulated vertical root fracture (VRF).

Methods: Sixty teeth, 30 with root fractures and 30 without, were examined through i-CAT tomography at 4 different voxel resolutions (0.125, 0.2, 0.3, 0.4 mm). Three observers scored the presence of VRF in all modalities. Sensitivity, specificity, likelihood ratio, and accuracy were calculated for each modality. Results: Chi-square statistical analysis showed no significant difference among the resolutions or observers. However, positive likelihood ratio values of 24.5 for a 0.125-mm voxel, 24.25 for a 0.2-mm voxel, 13.2 for a 0.3-mm voxel, and 13 for a 0.4-mm voxel were found. Accuracy results confirmed the likelihood ratios as 0.97, 0.96, 0.93, and 0.92, respectively. Conclusions: CBCT scans were reliable in detecting simulated VRF, and a 0.2-mm voxel was the best protocol, considering the lower x-ray exposure and good diagnostic performance. (J Endod 2011;37:75–79)

Key Words
Cone-beam computed tomography, diagnosis, vertical root fracture, voxel

Vertical root fractures (VRFs) are difficult to diagnose by conventional periapical radiography (CPR), and they can be overlooked if the x-ray beam does not pass along the fracture line. Thus, 2 or more radiographs taken at different angles are recommended (1, 2). Two-dimensional (2D) intraoral radiography systems fail to provide information regarding teeth and adjacent structures in the third dimension, and the superimposition of other structures further limits sensitivity (3). Thus, a need exists for an imaging system that provides 3-dimensional (3D) information in treatment assessment of root canal systems.

Recently a 3D diagnostic imaging system, cone beam computed tomography (CBCT), has been reported to be more accurate than CPR for detecting longitudinal root fractures with high image quality, permitting direct visualization of fracture lines, which are masked in CPR (4, 5). CBCT scans have been found to be more accurate in detecting VRFs in many studies (5–10). CBCT has been found to perform better than CPR and other intraoral techniques in detecting VRFs; however, many studies have concluded that the radiation doses from CBCT were higher than from conventional dental radiography techniques (11).

Briefly, digital images are composed of elements called pixels. A pixel is a picture element, a square in a 2D matrix. Each pixel has a specific size, intensity value, and location within the matrix. A voxel is a volume element, and it is the cubed form of a pixel, having a third dimension. Three-dimensional images are composed of voxels instead of the pixels in 2D digital images. The size of each voxel is determined by its height, width, and thickness, and a voxel is the smallest element of the 3D radiographic image volume (12, 13). CBCT images use isotropic voxels, meaning they have the same height, width, and thickness. The isotropic nature of the voxels affords the same quality as the original image in reconstructions.

Image quality has been described as the visibility of diagnostically important structures in the CT image (14, 15), and a number of factors affect image quality such as the milliamperage settings, voxel size, field of view (FoV), and detector type of the scanner (15–17). Diagnosis with CBCT offers 3D images without superposition of adjacent structures, and it is also a noninvasive technique with high accuracy (18–23). However, the radiation dose is equivalent to that needed for 4–15 panoramic radiographs (11), and unfortunately, image quality is directly related to radiation exposure (24). Voxel size has been reported to have a positive correlation with image quality (contrast and resolution) and exposure dose (6, 25).

ALARA is the acronym for as low as reasonably achievable and is a basic principle for diagnostic radiology. Keeping the dose as low as possible while still obtaining the needed information constitutes the basis of this principle (26).

It is known that with smaller voxel sizes, radiation exposure would be higher (12, 24, 27). Without sacrificing image quality and adopting the ALARA principle, the ability to select various voxel settings would be helpful in reducing the radiation dose to the patient. Thus, we compared the diagnostic accuracy of different voxel sizes for the detection of experimentally induced VRFs.

Materials and Methods

The experimental group consisted of 60 recently extracted human maxillary premolars, inspected with a stereomicroscope (MT4200 binocular; Meiji Techno
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**Table 1. VRFs Identified from a Total of 60 Teeth with Different Voxel Resolutions by 3 Observers**

<table>
<thead>
<tr>
<th>Voxel size (mm)</th>
<th>Observer 1</th>
<th></th>
<th>Observer 2</th>
<th></th>
<th>Observer 3</th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>True</td>
<td>False</td>
<td>True</td>
<td>False</td>
<td>True</td>
<td>False</td>
<td>True</td>
</tr>
<tr>
<td>0.125</td>
<td>55</td>
<td>5</td>
<td>60</td>
<td>0</td>
<td>59</td>
<td>1</td>
<td>174</td>
</tr>
<tr>
<td>0.2</td>
<td>57</td>
<td>3</td>
<td>58</td>
<td>2</td>
<td>58</td>
<td>2</td>
<td>173</td>
</tr>
<tr>
<td>0.3</td>
<td>56</td>
<td>4</td>
<td>58</td>
<td>2</td>
<td>54</td>
<td>6</td>
<td>168</td>
</tr>
<tr>
<td>0.4</td>
<td>55</td>
<td>5</td>
<td>55</td>
<td>5</td>
<td>56</td>
<td>4</td>
<td>166</td>
</tr>
</tbody>
</table>

X² test

\[ P = .7 \]

(Xk) Ltd, Axbridge, Somerset, UK) for the absence of VRFs. An access opening was made for each tooth, and the root canals were prepared with the ProTaper rotary system (Dentsply/Mailefer, Tulsa, OK) up to size F3. The teeth were divided into 2 groups of 30, with root fractures or intact. Root fractures were generated in the vertical plane according to a protocol reported in the literature (6). Five tooth roots broke into more than 3 fragments and were excluded from the study. Two fragments for 30 teeth were relocated with glue (Scotch Gel Universal; 3M, Leiden, The Netherlands). One human mandible was coated with 3 layers of dental wax buccally and lingually to simulate soft tissue and to reduce artifacts in the image (28). An observer who was not involved in preparation placed the teeth into sockets of the mandible at the most suitable position mesiodistally. They were held in place in the alveolar socket with boxing wax and were coded during imaging sessions.

**CBCT Scans and Data Treatment**

All images were evaluated by 3 observers (2 endodontists and 1 radiologist) at different sessions. CBCT images were scanned by using i-CAT CBCT (120 kVp, 5 mA; Imaging Sciences, Hatfield, PA). Scans of the mandible were made with 4-cm FoV selection at 4 resolutions: 0.125-mm voxel (4 seconds for acquisition), 0.2-mm voxel (4 seconds for acquisition), 0.3-mm voxel (7 seconds for acquisition), and 0.4-mm voxel (7 seconds for acquisition). Four-second and seven-second acquisition periods with shorter scanning time were selected to reduce radiation dose, even though i-CAT has longer scanning acquisition time was not restricted, and at a 1-week interval, the same observations were repeated. Weighted kappa coefficients were calculated to assess intraobserver and interobserver agreement.

The 4 voxel resolutions (0.125, 0.2, 0.3, 0.4 mm) were analyzed for standardization of image quality. Observers had been trained and calibrated for reading CBCT in a previous pilot study. Each observer evaluated the 4 voxel resolutions (0.125, 0.2, 0.3, 0.4 mm) by using axial, sagittal, and coronal directions, and a single score was obtained for each tooth. Observers were not informed that some teeth were intact without fractures. Observation time was not restricted, and at a 1-week interval, the same observations were repeated. Weighted kappa coefficients were calculated to assess intraobserver and interobserver agreement.

The 4 voxel resolutions (0.125, 0.2, 0.3, 0.4 mm) were analyzed independently by \( \chi^2 \) test at 5% significance. Sensitivity, specificity, positive likelihood ratio, and accuracy were evaluated for diagnostic performance according to the different voxel resolutions.

The fracture/non-fracture assessment was scored binarily: 1 if a fracture was present or 0 if it was not. Fracture/non-fracture scores were evaluated as follows: correct identification of a non-fractured root (true negative [TN]), correct identification of fracture site in a fractured root (true positive [TP]), identification of a fracture in a non-fractured root (false positive [FP]), incorrect identification of a fracture site in a fractured root (false negative [FN]), and failure to identify a fracture in a fractured root (false negative [FN]).

Sensitivity and specificity among the 4 modalities (0.125-, 0.2-, 0.3-, 0.4-mm voxel) were calculated as follows: Sensitivity = (TP/TP) + FN, Specificity = (TN/TN) + HP, Positive Predictive Value = (TP/TP) + FP, Negative Predictive Value = (TN/TN) + FN, Accuracy = (TP + TN)/(TP + TN + FP + FN), Positive Likelihood Ratio = Sensitivity/(1 − Specificity).

**Results**

Intraobserver kappa values were above 0.86, indicating very good intraobserver agreement.

Table 1 shows the number of true (TP + TN) and false (FP + FN) readings among the 3 observers and 4 different voxel resolutions. On the basis of the observed \( \chi^2 \) test results, no difference \( (P = .06) \) was found among voxel sizes or observers \( (P = .7) \).

Table 2 shows the results of diagnostic performance tests according to voxel resolution. The results indicate that voxel sensitivity and specificity values were similar; the highest accuracy was attained with 0.125 mm (97%) and in descending order, 0.2 mm (96%), 0.3 mm

**Table 2. Results of Diagnostic Performance Test with Different Variables at 4 Voxel Resolutions**

<table>
<thead>
<tr>
<th>Voxel size (mm)</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive predictive value</th>
<th>Negative predictive value</th>
<th>Accuracy (%)</th>
<th>Positive likelihood ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.125</td>
<td>0.98</td>
<td>0.96</td>
<td>0.95</td>
<td>0.98</td>
<td>97</td>
<td>24.5</td>
</tr>
<tr>
<td>0.2</td>
<td>0.97</td>
<td>0.96</td>
<td>0.95</td>
<td>0.97</td>
<td>96</td>
<td>24.25</td>
</tr>
<tr>
<td>0.3</td>
<td>0.93</td>
<td>0.93</td>
<td>0.93</td>
<td>0.93</td>
<td>93</td>
<td>13.2</td>
</tr>
<tr>
<td>0.4</td>
<td>0.91</td>
<td>0.93</td>
<td>0.91</td>
<td>0.91</td>
<td>92</td>
<td>13</td>
</tr>
</tbody>
</table>

Significance of \( \chi^2 \) test for observers’ voxels is defined as \( P \) value.
(93%), and 0.4 mm (92%). Furthermore, the positive likelihood ratio results are better with 0.125-mm and 0.2-mm voxel sizes (24%–24.25%) than with 0.3-mm and 0.4-mm voxel sizes (13%–13.2%).

**Discussion**

The diagnosis of VRF is usually problematic because it often necessitates prediction rather than a definite identification (28). Because radiographs and CBCT scans acquired by using different imaging parameters cannot exactly visualize these fractures (29, 30), the location and defect size cannot always be objectively assessed until the tooth has been extracted or a simultaneous flap operation has been performed for direct visualization. Also, determining the position and extent of the fracture might be helpful to decide when to recommend extraction or treatment possibilities. The detection of VRF is usually not performed
during treatment, which leads to bone loss, pain, and malfunction of the involved area discomforting the patient maybe for years (31). Thus, identification of the problem in early stages as soon as the problem gets more complex is quite important.

The present study compared the diagnostic accuracy of CBCT scans with different voxel resolutions in the detection of simulated VRFs. The dental CBCT, i-CAT, chosen for this study has been shown to be more accurate than digital and conventional 2D intraoral techniques in detecting VRFs (5–7, 10). Hassan et al (6) compared 5 different CBCTs for the detection of VRFs and reported that the Next Generation i-CAT was the most accurate system (with a voxel of 0.25 mm), followed by the Scanner 3D (voxel of 0.2 mm), Accuitomo-XYZ (voxel of 0.25 mm), Newtom 3G (voxel of 0.2 mm), and Galileos 3D (voxel of 0.3 mm). Generally, performance was better with 0.25-mm and 0.2-mm voxels than with the 0.3-mm voxel size.

When Wenzel et al (7) evaluated the diagnostic accuracy of CBCT and a photostimulable storage phosphor plate system (PSP) to detect VRFs, they used an i-CAT scanner with a 0.125-mm and 0.25-mm voxel sizes. Higher accuracy was reported with the smaller voxel sizes; 0.125-mm voxels showed a specificity of 98 and sensitivity of 87. A 0.25-mm voxel resolution was more accurate than the periapical PSP system, and high-resolution scanning was recommended in cases of suspected VRF that could not be visualized in periapical images.

Also, in an in vitro study to detect VRF by using CBCT, Kamberouglu et al (10) compared 2 different CBCT units with varying resolutions of 0.19-, 0.1-, and 0.3-mm voxel sizes. The 0.19-mm and 0.1-mm voxel resolutions achieved better results than the 0.3-mm resolution, but with higher reconstruction times, meaning more radiation exposure.

Liedke et al (25) also used i-CAT in assessing diagnostic ability in the detection of simulated external root resorption with different voxel resolutions (0.2, 0.3, 0.4 mm); the best results were achieved with a voxel size of 0.2 or 0.3 mm. According to the ALARA principle, the 0.3-mm voxel size with a shorter scanning time was recommended to reduce the patient’s x-ray exposure. Tanimoto et al (24) reported that choosing a small voxel size without changing the radiation dose increases the resolution.

In the present study, no significant differences were found among observers or voxel sizes, and the sensitivity/specificity results were high for all groups (sensitivity/specificity for 0.125 mm, 98.96; 0.2 mm, 97/96; 0.5 mm, 93/93; 0.4 mm, 91/93). The values revealed that all groups were similar in terms of sensitivity and specificity. The positive likelihood ratio showed that the 0.125-mm and 0.2-mm voxel resolutions were better than the 0.3-mm and 0.4-mm voxel resolutions (24.5, 24.25, 13.2, and 13, respectively) (Fig. 1). Accuracy results also showed that the 0.125-mm and 0.2-mm resolutions were more successful than the 0.3-mm and 0.4-mm resolutions in detecting VRFs, although the latter 2 voxel resolutions are also acceptable under clinical conditions (Fig. 1). However, there were cases identified as “False-Negative” in readings that failed to identify a fracture in a fractured root in all voxel sizes. Those might have resulted from low signal-to-noise ratio as a result of decreasing acquisition time to reduce the radiation dose.

The 4 voxel resolutions showed similar results in detecting simulated VRFs. However, accuracy was higher and the decision was easier with 0.125-mm and 0.2-mm voxels. The best voxel selection would be 0.2 mm, with a shorter scanning time and reduced radiation exposure to the patient.

Conclusions

CBCT is a reliable imaging system to detect VRFs, and considering the ALARA principle, 0.2-mm resolution is the best choice for diagnostic use.

References


