Analysis of the Width of Vertical Root Fracture in Endodontically Treated Teeth by 2 Micro–Computed Tomography Systems

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Abstract

Introduction: Early detection of vertical root fracture (VRF) is important for clinical endodontic practice. The purpose of this study was to measure the fracture width (distance between 2 sides of the fracture) of VRF teeth *in vitro* by using 2 micro–computed tomography (μ-CT) systems with different spatial resolution and voxel size. **Methods:** Thirty-seven endodontically treated teeth with VRF were scanned by 80-μm pixel size μ-CT. Fifteen teeth with no obvious fracture line, blurred image, or fracture space less than 100 μm were scanned by 9-μm pixel size μ-CT. **Results:** Presence of 2 VRF lines was more common in premolars (82%) than in molars (53%). In 7 premolars (32%) and 9 molars (60%), the VRF lines extended to within the apical 3 mm of the root. All fracture lines were detected by 9-μm pixel size μ-CT, but only 22 of 37 VRF teeth had vertical fracture identified by 80-μm μ-CT. From μ-CT examination, none of the fracture lines showed consistent and uniform fracture space. If 2 fracture lines were present, they were typically in opposite (not linear) directions. There was a significant correlation between 2 fracture lines or fracture lines extending within the 3 mm of the apex and fracture width greater than 100 μm. **Conclusions:** Application of 9-μm μ-CT can be accurately used for early detection of VRF. Fracture characteristics (eg, number of fracture lines, extension of fracture line) may affect the fracture width. Appropriate use of μ-CT technology can be helpful for early diagnosis of VRF. *(J Endod 2014;40:698–702)*

Key Words

Cone-beam computed tomography (CBCT), endodontically treated teeth, micro-computed tomography (μ-CT), vertical root fracture (VRF)

Definitive diagnosis of vertical root fracture (VRF) in clinical dental practice is important to avoid unnecessary endodontic retreatment or periapical surgery. In addition, prolonged infection, inflammation, and swelling caused by VRF compromise adjacent alveolar bone used in implant placement and prosthetic reconstruction. However, definitive diagnosis of VRF in endodontically treated teeth by using periapical radiographs is problematic (1–4). Recent research has focused on the development of appropriate non-radiographic methods to detect VRF; however, current techniques are inadequate (5–7).

Although 2-dimensional radiography with image processing by fractal dimension method can be helpful in evaluating the outcome of endodontic treatment (8), 3-dimensional imaging with computed tomography (CT) allows for earlier evaluation of apical healing (9). Since the introduction of cone-beam CT (CBCT) in dental treatment, endodontists have used CBCT in the evaluation of root canal distribution, detection of apical lesions, verification of horizontal and vertical root fracture, and the diagnosis of odontogenic infection (10–14). Studies evaluating CBCT in VRF have shown higher sensitivity and specificity than periapical radiographs in detecting artificial fracture lines in teeth (15–22).

The spatial resolution of CBCT images depends on the voxel size of the detector, focal spot, kV, and different CBCT settings (23). The smaller voxel size translates into higher resolution of CBCT. Prior studies used CBCT to detect artificially created VRF and evaluated different CBCT parameters (18). One case report described 140-μm spatial resolution of flat panel volume detector computer tomograph system in 5 VRF teeth (24). However, longitudinal root fracture may require higher resolution for detection. Knowing the possible width of fracture in VRF teeth helps to delineate CBCT with adequate voxel size and spatial resolution to detect the presence of longitudinal root fracture.

VRF may show 1 or 2 fracture lines in roots (25). The possible correlation between the number of fracture lines and width of the fracture is an interesting issue awaiting investigation. Micro-CT (μ-CT) with higher spatial resolution and very small voxel size could be a tool to analyze tooth structure without distortion (26, 27). Because different μ-CTs have differential spatial resolution, voxels, and computer memory, this study used an endodontic microscope and 2 μ-CT systems with different voxel size and spatial resolution to measure the vertical fracture width in endodontically treated teeth.

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Materials and Methods

Sample Collection and Preparation

Thirty-seven VRF teeth (15 molars and 22 premolars) were collected by 8 endodontists during the previous 5 years (2007–2011). These study teeth were extracted after clinical diagnosis of VRF, which was confirmed microscopically after surgical exposure of the root surfaces. After removal of the granulation tissue on the root surface, the teeth were placed in formalin and stored at 4°C. Two teeth (1 molar and 1 premolar) without crown/root fracture were extracted and preserved in dry conditions for 3 years to serve as control. Only teeth extracted without evident root surface damage were included in this study.

Microscope Examination

All study teeth were soaked in 5% β-iodine solution for 5 minutes. The number of VRF lines on the root surfaces was observed under microscope (Moller-Wedel Denta 300, Wedel, Germany) with $\times$4 and $\times$8 magnifications. For inclusion in the study, all study teeth must have had at least 1 VRF line on the root surface confirmed by 2 endodontists. The number of fracture lines and any fracture lines extending to within the apical 3 mm of the root apex were recorded.

Micro-CT Image (Image Voxel Size: 80 μm Mode) Acquisition

All study teeth were scanned by μ-CT (Triumph X-O CT System; Gamma Medica Ideas, Northridge, California) with the following parameters: 80 kV, 90 μA, field of view 29.59 mm, acquisition time 5 minutes, and 512 slices. The images were imported into DICOM file format and visualized and analyzed with Mimics software (Mimics Innovation Suite, Leuven, Belgium). After μ-CT scanning, the 37 study teeth were divided into 4 groups on the basis of the width of the fracture: group A (fracture line detected by 9-μm μ-CT, but not in 80-μm mode μ-CT), group B (fracture width < 100 μm), group C (fracture width between 100 and 200 μm), and group D (fracture width > 200 μm) (Table 1).

Micro-CT Image (Image Voxel Size: 9 μm) Acquisition

The 2 control teeth and 15 study teeth (7 molars and 8 premolars) with fracture < 100 μm (not detected or obscured by the 80-μm mode CT acquisition) were scanned again by μ-CT (Skyscan 1076; BRUKER MICROCT, Kontich, Belgium) with higher resolution (9-μm mode). The scanned parameters were 49 kV, 139 μA, field of view 25 mm, acquisition time 21 minutes, and 2000 slices. The images were imported into DICOM file image and visualized by the Mimics software.

Measurement of Maximal Fracture Space by μ-CT Image Analysis

Sequential slices of μ-CT images were taken, and VRF appearance and disappearance were recorded (Fig. 1*A*). One transverse section in the middle of the VRF line was used to measure the maximum VRF space. The width of the fracture was measured at 3 points (S1, S2, and S3) (Fig. 1*B*). The widest distance at S1, S2, and S3 was regarded as the maximum width of the fracture. If 2 fracture lines were present, the larger fracture line was recorded.

Statistical Analysis

The Fisher exact test was used to evaluate whether fracture width > 100 μm and $\leq$ 100 μm and extension of the fracture line to within the apical 3 mm of the root apex were associated with the number of fracture lines.

TABLE 1. Number (percentage) of Teeth (n = 37, 15 molars, 22 premolars) with Different VRF Spaces as Detected by 2 Modes of μ-CT

	Total	Molar	Premolar
Group A	2 (13)	3 (14)	5 (11)
Group B	5 (33)	5 (23)	10 (27)
Group C	5 (33)	12 (55)	17 (46)
Group D	3 (20)	2 (9)	5 (14)

Group A, fracture line detected by 9-μm μ-CT, but not in 80-μm mode μ-CT; group B, detected fracture space < 100 μm; group C, width of the fracture between 100 and 200 μm; group D, width of the fracture > 200 μm.

Results

Microscope View

All study teeth (15 molars, 22 premolars) showed 1 or 2 fracture lines on the root surface as observed under a microscope (Fig. 1*C*). The presence of 2 fracture lines was more common in premolars (18 of 22, 82%) than in molars (8 of 15, 53%) (Table 2). In 7 premolars (7 of 22, 32%) and 9 molars (9 of 15, 60%), the VRF extended to within 3 mm of the root apex (Fig. 1*D*).

Micro-CT Image (Image Voxel 80 μm) Acquisition and Fracture Space Analysis

In group A (5 teeth), no fracture line was detected in the 80-μm mode μ-CT. In group B (10 teeth), the fracture line was obscure in the 80-μm μ-CT (Fig. 1*E*). Fracture lines were clearly visualized in group C (17 teeth) and group D (5 teeth) by using 80-μm μ-CT (Fig. 1*F*).

Micro-CT Image (Image Voxel 9 μm) Acquisition in the Control Teeth

The control molar showed no marked fracture line by using 9-μm μ-CT. Three fracture lines extending from cementum into root dentin from different directions were detected in the control premolar. The 3 fracture lines disappeared near the root canal wall and did not merge.

Micro-CT Image (Image Voxel 9 μm) Acquisition and Fracture Space Analysis

Fracture lines were not consistent and regular in the root dentin. None of the teeth had uniform width fractures as observed under μ-CT. If 2 fracture lines were present, they were often in opposite (non-linear) directions.

The mean widths of the fractures measured at S1, S2, and S3 were 133 $\pm$ 28.4, 131 $\pm$ 27.0, and 128 $\pm$ 26.9 μm, respectively (P > .05) (Table 2).

Although fracture lines in groups A and B could not be clearly identified by the 80-μm μ-CT, fracture lines were detected by 9-μm μ-CT. As shown in Figure 1*G*, no marked fractures were seen on images from the 80-μm μ-CT, whereas fracture lines were detected in sequential 9-μm μ-CT images.

Sequential transverse sections of 9-μm μ-CT images from root apex to cementoenamel junction (Fig. 1*H–L*) showed that the first fracture line started from outer cementum surface near the apex; the fracture did not originate from the inner root canal (Fig. 1*H*). The fracture line subsequently extended through dentin into the root canal wall (Fig. 1*I*). As the VRF extended coronally, the width of the fracture enlarged. In all cases, the maximal fracture space was present in the mid-root section. As the size of the first fracture decreased, a second fracture line was detected in the contralateral side of the middle root (Fig. 1*J*). The second fracture line extended through the dentin into cementum of the outer root surface (Fig. 1*K*). Moving coronally, the 2 fracture lines merged in the root canal, and the size of the first fracture line decreased (Fig. 1*L*).

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