Comparing the *In Vivo* Diagnostic Accuracy of Digital Periapical Radiography with Cone-beam Computed Tomography for the Detection of Vertical Root Fracture

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Abstract

Introduction: The purpose of this study was to determine whether there is a difference in the *in vivo* diagnostic accuracy of digital radiography (DR) and cone-beam computed tomography (CBCT) imaging in the detection of vertical root fracture (VRF). The presence/absence of VRF was confirmed by visual inspection of the extracted root surface and was the reference standard against which both imaging modalities were compared. **Methods:** Twenty-one unsalvageable teeth from 20 patients that had been radiographed and scanned with CBCT imaging were included in the study. The teeth were atraumatically extracted and visually inspected under a microscope to confirm the presence/absence of fracture. The widest point of each fracture was recorded using an optical coherence tomography scanner in order to quantify the size of fractures. Images were viewed under standardized conditions by 13 examiners and repeated 2 weeks later to assess their consistency. **Results:** DR and CBCT imaging showed similarly poor sensitivity of 0.16 and 0.27, respectively. Both imaging modalities had similarly high specificity of 0.92 and 0.83, respectively. There was no statistical difference between the diagnostic accuracy of either imaging modality. Fracture width did not affect the detection rate of either imaging modality. Receiver operating characteristic analysis revealed mean A_z values of 0.535 and 0.552 for DR and CBCT imaging, respectively. **Conclusions:** Both DR and CBCT imaging have significant limitations when detecting vertical root fractures. *(J Endod 2014;40:1524–1529)*

Key Words

Cone-beam computed tomography, digital radiography, *in vivo*, vertical root fracture

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Complete or incomplete vertical root fracture (VRF) develops longitudinally along the root (1). Incomplete root fractures are notoriously difficult to diagnose (2). Classic clinical findings include the presence of an isolated deep periodontal pocket (3) and crestally located sinus tracts (4). However, it is difficult to reach a definitive diagnosis on the basis of signs and symptoms alone because they are not specific to fractures and are very similar to endodontic or periodontal disease (5).

The presence of a VRF is usually associated with a poor prognosis of the affected tooth (6). Chen et al (7) evaluated the outcome of 857 endodontically treated teeth over a 5-year follow-up period. They reported that of the 64 teeth that required extraction, VRF was identified as the cause of extraction in 32.1% of teeth.

The diagnostic yield of conventional digital radiography (DR) is limited by its 2-dimensional nature (8). Rud and Omnell (9) evaluated 375 fractured teeth using DR and reported that only 35.7% of root fractures were detected radiographically. Meister et al (2) suggested that VRF is only directly detected with DR if there is separation of the root fragment and if the fracture traverses in the direction of the x-ray beam. If the fracture is not in the plane of the beam, the clinician is forced to make interpretations based on periradicular bone loss. Common radiographic signs include the presence of "halo or J-shaped" radiolucency around the root, lateral periodontal radiolucencies alongside the root, or angular radiolucencies in the crestal bone that terminate alongside the root (4, 10, 11).

Cone-beam computed tomography (CBCT) imaging enables the clinician to view the tooth from multiple planes and different angles, which may overcome the limitations of DR (12, 13). Fayad et al (14) suggested 5 specific CBCT findings that were consistent in the presence of clinically confirmed VRFs. These include loss of bone in the midroot area with intact coronal bone, absence/loss of the buccal plate, radiolucency at the terminus of the restorative posts, radiolucency between the cortical plates and the root surface, or visualization of the fracture of the CBCT volume. However, because most VRFs are associated with endodontically treated teeth, there needs to be consideration for the creation of reconstruction artifacts in the presence of materials within the root canal (15).

Previous *ex vivo* studies have shown that CBCT imaging is superior to DR for the detection of artificially created VRFs (16–19). However, *ex vivo* studies do not account for patient factors such as the effect of surrounding tissues or the possibility of motion artifacts during scanning.

Recent *in vivo* studies have reported higher sensitivity and specificity for CBCT imaging in the diagnosis of VRF when compared with DR (20–23). Bernardes et al (20) determined the presence of root fracture based on clinical signs and symptoms. Other studies have used a combination of surgical exploration, orthograde retreatment, root amputation, or extraction to confirm the absence or presence of root fracture as the reference standard to which the imaging modalities were compared (21, 23). Surgical exploration is limited in visualizing the palatal/lingual aspect of the root surface, and orthograde access does not allow complete internal inspection of the root canal wall, especially in the apical region. To date, Wang et al (22) is the only *in vivo* study that has comprehensively assessed the entire root surfaces of extracted teeth in order to confirm the presence of fractures.

The purpose of this *in vivo* study was to determine whether there is a difference in the diagnostic accuracy of DR and CBCT imaging in the detection of VRF. Visual inspection of the root surface in order to confirm the presence/absence of VRF was the reference standard against which both imaging modalities were compared. Optical coherence tomographic (OCT) imaging was used to measure the width of fracture in order to assess whether fracture size impacts on the diagnostic accuracy of either imaging modality.

Materials and Methods

The study was approved by a National Health Service Research Ethics Committee (13/NI/0180) at the Office for Research Ethics Committees Northern Ireland.

Sample Selection

Twenty-two teeth from 21 patients were included in the sample. Each tooth had been deemed unsalvageable after a thorough clinical examination by an experienced endodontist working in a specialist private practice (Tables 1 and 2)

Each tooth was atraumatically extracted in order to minimize possible intraoperative fracture creation. The epithelial attachment at the crestal level was severed using a periosteal elevator (PT1 Periotome; HuFriedy, Chicago, IL) before application of a sharp luxator (Luxator Forte Elevator 4 mm; Directa, Upplands Vasby, Sweden). Once sufficiently luxated, artery hemostats were used to deliver the tooth out of the socket. Multirooted teeth were sectioned first with a surgical handpiece (S 9 LG Angled handpiece; W&H, Brusporto, Italy) using a long tapered endo access bur. The extracted teeth were stored in a formal saline medium in order to prevent desiccation and changes to the physical properties of the root surface while in storage. Each root surface was cleaned with a toothbrush and then visually inspected under a dental operating microscope at 12.0× magnification (Global G4; DP Medical Systems, UK) to confirm the presence or absence of root fractures, after which magnified high-resolution photographs (AZ100 Multizoom Microscope; Nikon Instruments, BV, Amsterdam, Netherlands) were taken. A fracture was deemed to be present if there was separation of the root fragment or a dark line traversing along the root surface.

Measurement of Fracture Width

OCT is a high-resolution imaging technique that allows micrometer scale imaging of biologic tissues over small distances. It uses infrared waves that reflect off the internal structure within the biologic tissues. It achieves a depth resolution in the order of 10 μm (24).

The surface of each tooth was scanned along the entire length of each crack at 0.2-mm intervals using an OCT scanner (VivoSight; Michelson Diagnostics Limited, Maidstone, UK). The OCT scans were viewed using Image J (National Institutes for Health, Bethesda, MD). The widest point of the crack on the surface of the root was identified and noted. The maximum width of fracture in this study ranged from 60–770 μm. The teeth were divided into 2 groups: the first one included teeth with fracture widths of $\geq$300 μm and the second included fracture widths <300 μm.

TABLE 1. Breakdown of the Sample by Root-filled and Non–root-filled Teeth

	Molars	Premolars	Incisors	Total
Root filled	13	3	1	17
Unfilled	4	0	1	5
Total	17	3	2	

Radiographic Technique

Digital radiographs were taken using a charge-coupled device sensor (Schick Technologies, New York, NY) and a standard dental x-ray unit (Prostyle Intra X-ray Unit; Planmeca, Helsinki, Finland) with the exposure parameters set to 66 kV, 7.5 mA, and 0.10 seconds. A beam aiming device (Dentsply Rinn, York, PA) was used to obtain straight and angled views.

CBCT scans were taken using a small-volume (40 mm^3) CBCT scanner (3D AccuitomoF170; J Morita, Kyoto, Japan) with exposure parameters of 90 kV, 5.0 mA, and 17.5 seconds. All CBCT scans were reformatted (0.125 slice intervals and 1.5-mm slice thickness).

Radiologic Assessment

Thirteen examiners (3 endodontists and 10 endodontic postgraduates) were recruited to assess the radiographs and CBCT scans. The postgraduates were either second- or third-year students with at least 2 years of experience in the interpretation of CBCT images. Observations were performed in a quiet, dimly lit room to optimize the viewing conditions. The radiographs were viewed on a desktop computer with a 17-inch monitor set to a screen resolution of 1280 × 1084 (Dell Optiplex 360, Microsoft Vista OS; Dell, Round Rock, TX). The images were presented as a Power Point presentation (Microsoft Corp, Seattle, WA). Each root was labeled with a colored arrow to avoid confusion. The CBCT image was presented as a series of axial slices that best showed whether a VRF was present. The reconstructed CBCT images were formatted to be aligned with the long axis of the tooth; 6–8 axial slices of each root were captured. Each slice was adjusted for brightness and contrast to improve visualization of any fractures. Examiners also had access to the raw CBCT data (One Data Viewer; J Morita, Kyoto, Japan), enabling them to scroll through any of the orthogonal scans if they felt they required more information. No other clinical information was provided. They were advised to disregard any associated periradicular radiolucencies (Fig. 1).

Examiners were calibrated beforehand with examples of DR and CBCT images with and without root fractures present obtained from teeth that were not within the study sample. The examiners were asked to record the presence/absence of a VRF using a 5-point confidence scale as follows: 1: VRF definitely not present, 2: VRF probable not present, 3: unsure, 4: VRF probably present, and 5: VRF definitely present.

The images were randomized, and observations were repeated approximately 2 weeks later in order to assess intraexaminer validity. Visual detection of a fracture using a dental operating microscope was the reference standard against which the examiners were compared (Fig. 2).

Statistical Analysis

Receiver operating characteristic analysis was used to determine the diagnostic accuracy of each examiner for detecting the presence/absence of a VRF. Calculations of sensitivity, specificity, positive predictive value, and negative predictive value were made. Chi-square tests were performed to compare whether there were significant differences in the detection of fractures with widths of $\geq$300 μm and those of <300 μm. Kappa analysis was used to assess inter- and intraexaminer agreement. Data were analyzed using Stata 10 software (StataCorp, College Station, TX).

Results

The results indicate that both DR and CBCT imaging have comparably poor sensitivity (0.16 and 0.27, respectively) and comparably