Detection of Vertical Root Fractures by Using Cone-beam Computed Tomography: A Clinical Study

Mitchell Edlund, DDS, * *Madhu K. Nair, DMD, MS, PhD,* [†] *and Umadevi P. Nair, DMD, MDS* *

Abstract

Introduction: Vertical root fractures of teeth (VRFs) often pose a diagnostic dilemma because of the difficulty in detection of these in intraoral radiographs except in certain cases with very distinct clinical findings. This often leads to unwarranted extraction of the tooth. Cone-beam computed tomography (CBCT) produces three-dimensional images and allows precise visualization and evaluation of VRFs or cracks in extracted teeth, as reported previously. This clinical pilot study was designed to determine the diagnostic accuracy of noninvasive CBCT for detection of suspected VRFs in endodontically treated teeth by using exploratory surgery to confirm the presence or absence of a fracture. **Methods:** Thirty-two teeth in 29 patients with clinical signs and symptoms suggestive of VRF were included in the study after informed consent was obtained. They underwent a limited area CBCT evaluation. All CBCT studies were blinded, and 2 board-certified oral and maxillofacial radiologists assessed the presence or absence of VRF through sequential evaluation of the three-dimensional volume. Subjects underwent surgical exploration as part of treatment, which helped establish the presence or absence of VRF. **Results:** Pearson correlation coefficient by using surgical finding to confirm presence/absence of fracture was 0.602, positive predictive value was 91%, and negative predictive value was 67%. The sensitivity was 88%, and specificity was 75%. **Conclusions:** This study revealed the superior diagnostic accuracy of CBCT for detection of VRF. *(J Endod 2011;37:768–772)*

Key Words

CBCT, radiograph, vertical root fractures

From the Departments of *Endodontics and [†]Oral and Maxillofacial Diagnostic Sciences, College of Dentistry, University of Florida, Gainesville, Florida.

Address requests for reprints to Dr Umadevi P. Nair, Assistant Professor, Department of Endodontics, College of Dentistry, University of Florida, 1600 SW Archer Road, Room D10-37, Gainesville, FL 32610-0436. E-mail address: unair@dental.ufl.edu
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The clinical presentation and radiographic appearance of a vertical root fracture (VRF) frequently pose a diagnostic dilemma to the clinician. Lack of definitive diagnosis often leads to unnecessary invasive surgery and/or extraction of the tooth (1). At times, a thorough dental history combined with classic clinical and radiographic signs and symptoms such as pain and swelling, presence of an isolated deep periodontal pocket, and a combination of periapical and lateral radiolucency associated with the root might provide valuable information indicating the possible presence of VRF; however, several elements have to align for it to be identifiable by these classic methods (2, 3). A VRF might also be observed directly on a conventional radiograph in the event the x-ray beam is in the same plane as the fracture to be observed (3). Often exploratory surgery is resorted to in order to visualize the fracture. This is done by raising a full-thickness flap to directly visualize the root(s) under light, magnification, and methylene blue staining. There is no substitute for direct visualization if the diagnostic and prognostic assessments remain questionable (1).

The inability of conventional imaging techniques to consistently visualize VRFs precisely necessitates the development of alternative imaging modalities to improve their detection (4). Cone-beam computed tomography (CBCT), also called digital volume tomography (DVT), is a relatively new imaging modality in maxillofacial imaging, which involves three-dimensional (3D) slice acquisition at significantly reduced radiation doses. Other reported advantages include reduced cost, faster and easier image acquisition, and a reduction in artifacts commonly encountered in conventional and spiral CT (5). CBCT units are available with variable fields of view (FoVs), which is the volume of data captured in the scan. Large-volume scanners include the iCAT unit (Imaging Sciences International, Hatfield, PA), which captures the entire maxillofacial skeleton. It can also be adjusted to capture only the maxilla or the mandible. The limited-volume CBCT units allow for the visualization of only 2 or 3 teeth (eg, 3D Accuitomo 80; J Morita Corporation, Kyoto, Japan). The reported effective radiation doses from different CBCT units vary and are directly proportional to the FoV (6). Various clinical applications in endodontics have been recently reported in literature, which include its use in diagnosis, presurgical treatment planning, studying the relationship of teeth to critical anatomical structures and root morphology, diagnosis of dentoalveolar trauma, and its potential application in determining the outcome of endodontic treatment (6, 7). CBCT technology might allow precise visualization and evaluation of VRFs in extracted teeth with clinically suspected root fractures (8, 9).

The intent of the study was not to identify the technical capabilities of a CBCT unit for detection to fractures but to investigate the superior diagnostic accuracy of 3D imaging to better delineate fractures, as compared with two-dimensional conventional projections. The aim of the following *in vivo* pilot study was to validate the diagnostic capability of CBCT with respect to VRF by using surgical exploration and direct visualization of the fractures to establish their presence/absence.

Materials and Methods

Subjects for this study were recruited from the patient pool seen in the Department of Endodontics. Institutional review board approval from the university was obtained before the commencement of the study. Informed consent was obtained from the patient at the time of enrollment into the study. Thirty-two teeth in 29 patients in the age group of 20–70 years who presented to the clinic with signs and symptoms of a suspected VRF

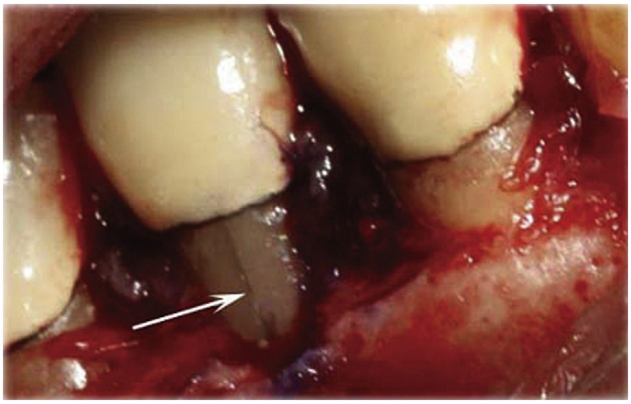

Figure 1. Surgical exploration visualizing fracture for validation of CBCT finding.

were included in the study. The following clinical features were evaluated for patient recruitment purposes:

- Pain on percussion and palpation
- Bone loss around the suspected tooth presenting as a narrow, deep periodontal pocket clinically
- Conventional radiograph presenting with bone loss on the mesial and distal parts of the root. Only cases in which VRF could not be seen radiographically were used.
- Only teeth previously treated endodontically were included. Patients who were poor candidates for endodontic surgery were excluded from the study. Exclusion criteria included patients with the following:
- Uncontrolled diabetes, severe periodontal disease, history of radiation therapy in the area, recent heart surgery or cancer surgery, and those on bisphosphonate therapy.
- Immunosuppressed and pregnant patients.

Patients whose periapical radiographs revealed a VRF as a distinct radiolucency, with or without other imaging findings usually associated with fractures such as localized osteolysis, were excluded from the study because these were not considered challenging cases. Only those patients in whom radiographic detection of VRF with conventional radiographic techniques was deemed impossible by the oral and maxillofacial radiologists were included in the study.

A comprehensive oral examination was completed on each patient presenting with VRF symptoms and/or signs. Periapical digital radiographs were acquired by using 2 different angulations (one straight on and one at a mesial angulation of approximately 30 degrees). Initial radiographs were used to screen for features in the inclusion criteria as well as to evaluate the presenting condition of the tooth (previous root canal therapy, post core and crown restorations, and localized crestal or apical bone loss). After enrollment into the study, patients underwent a CBCT study with a limited-area FoV. All studies were with protocol by radiologists. CBCT images were acquired with either the iCAT unit or the 3D Accuitomo 80 unit. All images were saved in DICOM format. Because this was a study validating the use of CBCT for detection of VRF, which was confirmed with surgical exploration, we decided to use the lowest possible voxel size (125 μm) with a limited FoV on a regular scanner capable of different FoV settings and more commonly used (iCAT) as

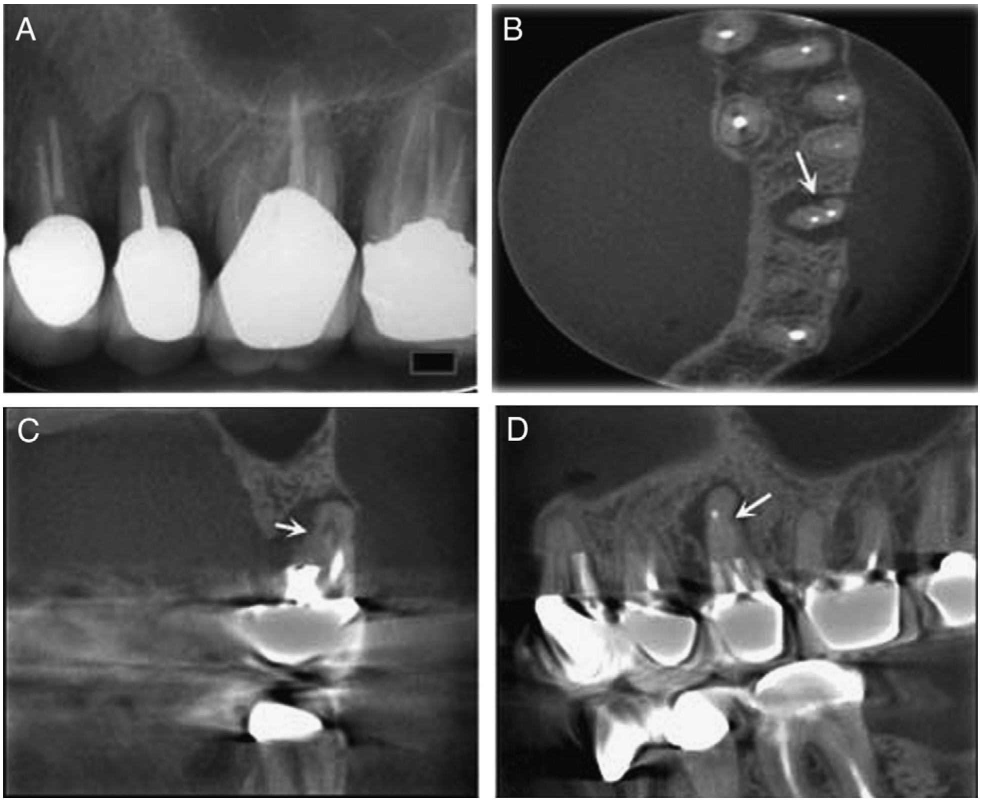

Figure 2. (*A*) Periapical radiograph of suspected tooth with VRF. (*B*) Axial CBCT view showing a fracture line running mesiodistally. (*C*) Coronal view. (*D*) Sagittal view.

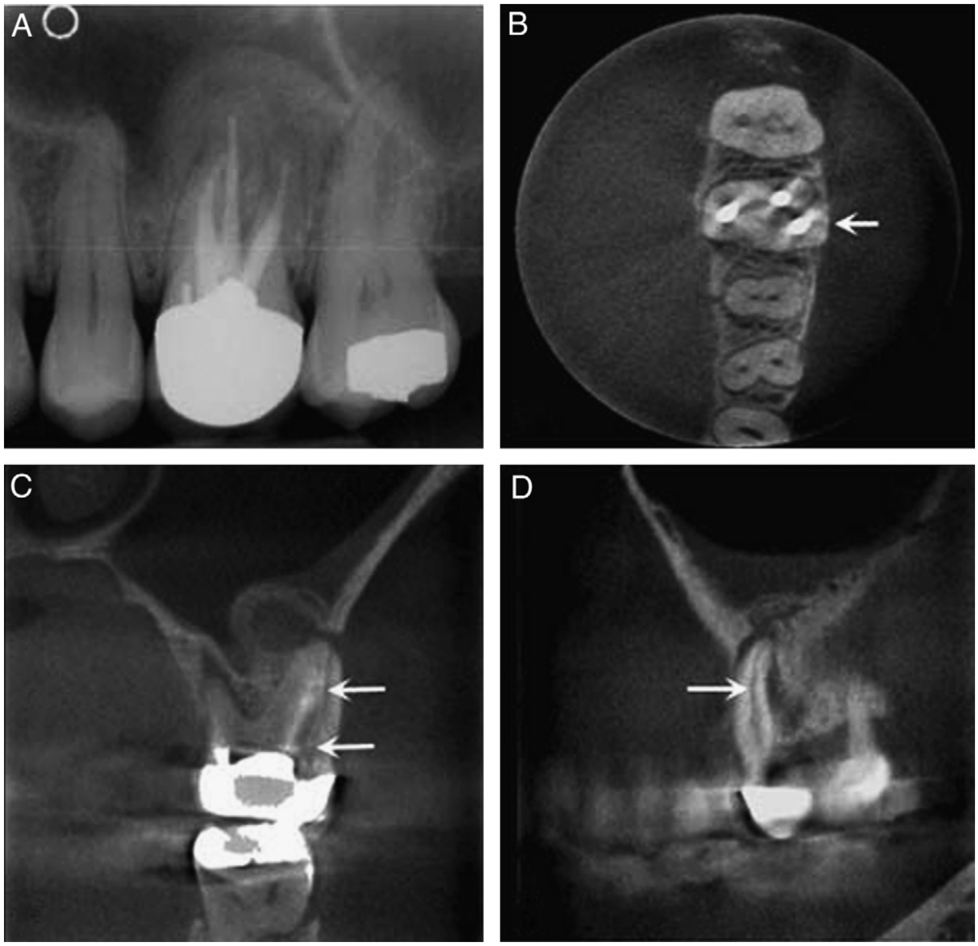

Figure 3. (*A*) Periapical radiograph of suspected tooth #14 with VRF. (*B*) Axial CBCT view showing a fracture line (*arrow*) on the mesiobuccal root. (*C*) Coronal view showing the full extent of the fracture (*arrows*) on the mesiobuccal root. (*D*) Sagittal view of the fracture (*arrow*). (*A* and *C*, Reprinted from Nair UP, Nair MK. Maxillary sinusitis of odontogenic origin: cone-beam volumetric computerized tomography—aided diagnosis. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology 2010;110:e53–e57, with permission from Elsevier.)

well as a unit offering a limited FoV with a significantly smaller voxel size of 80 μm (Accuitomo).

The subjects then underwent surgical exploration in the endodontic surgical suite, with the standard protocol for endodontic surgery. This procedure consisted of lifting a full-thickness mucoperiosteal flap and examining the bone and root directly with high magnification and illumination under an operating microscope (OPMI pico; Carl Zeiss, Oberkochen, Germany). A disclosing dye, methylene blue, was used to aid the surgeons in visualizing the fractures (Fig. 1). If a VRF was detected, the tooth was extracted, or another appropriate measure was taken such as root amputation. If no fracture was present, the site of interest was evaluated for the presence of any other pathology, and appropriate treatment was instituted. The patients with teeth that did not have a fracture were placed on routine recalls.

Data Collection and Analysis

CBCT images were blinded and viewed as a stack of slices by 2 board-certified oral and maxillofacial radiologists in DICOM format. Both radiologists underwent a calibration session with examples with known ground truth before reviewing the study cases. The radiologists were allowed to page through the stack and manipulate images interactively to simulate the clinical environment. The entire volume was evaluated following multiplanar reformatting (Figs. 2 and 3). 3D volumetric rendering was also done for interactive manipulation. Each volume was also inspected under different window settings that included bone and teeth settings. Each observer was told of *a priori* probability of lesion occurrence (0.5). Each observer was required to express subjective certainty of the presence or absence of a fracture on the basis of a 1–3 subjective confidence-rating Rikert scale (1, fracture definitely not present; 2, uncertain if fracture is present or not; 3, fracture definitely present).

Results

Scores 1–2 were considered negative for fractures, whereas score 3 was considered positive (Table 1). In addition to sensitivity and specificity, accuracy and positive and negative predictive values were computed as well. Sensitivity of CBCT for detection of VRF was 88%, and the specificity was 75%. Positive predictive value (PPV), the proportion of teeth with fractures that were correctly diagnosed, was determined to be 91%, and negative predictive value (NPV), the proportion of teeth with no fractures that were correctly diagnosed, was 67%. The overall accuracy was 84%.

The above values were computed on the basis of unit used as well. For the iCAT, sensitivity was 87%, specificity 71%, PPV 87%, NPV 71%, and accuracy 82%, whereas the Morita unit displayed sensitivity of 89%, specificity 100%, PPV 100%, NPV 50%, and accuracy 90%.

TABLE 1. Tooth Number, CBCT Unit, Dichotomized Score for CBCT and Surgical Visualization, and Clinical Presentation

Tooth no.	CT unit*	CT score†	Clinical score	Clinical presentation
25	2	1	1	RBL, PP
8	1	0	0	RBL, CBL
15	2	1	1	RBL, CBL, PP
30	2	1	1	PP
12	2	1	1	RBL, CBL
3	1	0	0	PP
20	1	1	1	RBL, CBL
19	1	1	1	RBL, CBL
18	1	1	0	CBL, PP
14	1	1	1	PP
3	1	0	1	PP
14	1	1	0	RBL, CBL, PP
12	1	1	1	CBL, PP
13	1	1	1	CBL
3	1	0	1	RBL, CBL, PP
3	1	1	1	RBL, CBL
13	2	1	1	RBL, PP
18	1	1	1	CBL, PP
18	1	1	1	CBL, PP
30	2	1	1	RBL, PP
13	2	0	1	RBL, CBL
3	1	0	0	CBL, PP
19	1	1	1	RBL, CBL, PP
19	2	0	0	RBL, CBL
3	1	1	1	RBL, CBL
6	1	1	1	RBL, PP
31	2	1	1	CBL
21	1	1	1	RBL, CBL, PP
14	2	1	1	RBL, CBL, PP
3	1	0	0	RBL, CBL, PP
3	1	1	1	RBL
14	1	0	0	RBL, CBL

RBL, radiographic bone loss; CBL, clinical bone loss; PP, pain on percussion.

*1, iCAT; 2, 3D Accuitomo 80.

†1, fracture present; 2, fracture absent.

Pearson correlation coefficient evaluating imaging diagnosis against surgical visualization was 0.602, indicating a large correlation. The correlation between clinical findings (clinical bone loss, radiographic bone loss on the preoperative periapical radiograph, and pain on palpation) and presence of fracture was not significant.

Discussion

This *in vivo* pilot study was intended to serve as a clinical trial to validate the diagnostic capability of CBCT in confirming suspected VRFs of teeth in patients. The prevalence of VRF has been reported to range from 10.9% (10) to 12.9% (11), with highest incidence occurring in an age group of 40–60 years (2, 12). The teeth most often affected were mandibular molars and maxillary premolars (12). Various factors have been attributed to the cause of these fractures (13, 14). Endodontically treated teeth and extensively restored teeth were shown to be predisposed to VRFs (15). Presence of posts in root canals accounted for 61.7% of root fractures (15). A recent study emphasizes the importance of identifying and reducing the risks for potential root fractures by avoiding the controllable factors, such as reinforcement of the roots of immature teeth with incomplete root formation after apexification, minimal removal of remaining sound tooth structure, placement of posts in only essential cases, sealing access cavities, and covering weakened cusps with permanent bonded restorative materials (16). The term *fracture necrosis* defines a tooth with a longitudinal fracture that extends into the pulp and causes necrosis. These teeth have poor prognosis, and extraction might be considered as the primary treatment option (17).

This pilot study did not show any correlation between the various signs and symptoms (presence of clinical bone loss, radiographic bone loss on a periapical radiograph, and pain on percussion) and the presence of fracture determined by surgical exploration. This is in agreement with the previous studies that have addressed the challenges in diagnosing a VRF on the basis of clinical presentation and two-dimensional radiographs (2, 3).

Various studies have determined the low sensitivity of conventional radiographs in the detection of VRFs. A recent *in vitro* study reported low sensitivity for conventional films (38%) and direct digital films (48%) for detection of VRF (18). Tuned aperture computed tomography (TACT), a 3D image forming algorithm, was shown to have greater diagnostic accuracy than conventional radiographs for detection of VRF in single-rooted, endodontically treated teeth in cadaveric mandibles (4).

CBCT provides for faster and easier image acquisition. Numerous *in vitro* studies support the validity of using CBCT to detect VRFs (9, 19). The detection of VRFs in root canal filled teeth had a sensitivity of only 51.4% in the buccolingual direction and 7.7% in the mesiodistal direction by using periapical radiographs in a recent *in vitro* study (19). The authors reported a higher sensitivity with CBCT in the buccolingual and mesiodistal directions (87% and 63.5%). The specificity of CBCT in the study was shown to be reduced as a result of the presence of root filling material. This could be related to streak artifacts and beam hardening caused by the presence of the filling material, which might mimic a fracture line (20–22). The *in vitro* results beg the question of the reliability of such technology in the human model. This study serves to close this gap. Our study showed the superior sensitivity and specificity of CBCT in the first clinical investigation that permitted validation of the imaging modality.

To our knowledge, only 2 other *in vivo* studies looking at VRFs have been published (22, 23). The study by Youssefzadeh et al (23) used a medical grade CT machine. Medical grade CT results in significantly higher doses of radiation to the patient, producing images with much lower resolution. The potential for significant dental artifacts from metallic restorations exists. Imaging times are significantly higher than those of CBCT units. Nonetheless, they found promising results, with an average sensitivity of 70% and specificity of 100% for CT in the diagnosis of VRFs. These teeth were not endodontically restored, thus eliminating any artifact generation from high attenuation objects within the canals. They also noted that the sensitivity of dental radiographs was 23% and specificity was 100%. Thus, it was shown that intraoral radiographs, being two-dimensional in nature, performed poorly in comparison with images showing the third dimension. A second clinical study compared CBCT with conventional radiographs and reported the superior diagnostic accuracy of CBCT for detection of VRFs. However, a significant limitation of this study was that only the clinical findings were correlated with the radiographic findings, without establishing the actual presence or absence of VRFs through direct visualization of the fracture (22). If a fracture was present but the images did not pick it up, a false-negative scoring can be erroneously made. Thus, our study is the first one of its kind in the literature to validate CBCT for the diagnosis of VRF through establishment of its presence with surgical visualization. A recent systematic review addressed the need for more evidence-based data for clinical and radiographic diagnosis of VRFs (24).

The results of our *in vivo* study corroborate results of previous *ex vivo* models (23, 25). Our results clearly show the effectiveness of CBCT technology in detecting VRFs in patients with relatively high sensitivity and specificity. Two different CBCT units were used for the study (iCAT and Accuitomo). This project was intended only to validate CBCT in a clinical scenario for detection of VRF. It was not the intent to further define the technical and exposure parameters of the imaging units for the specific diagnostic task of interest. Further studies are currently in progress to evaluate and establish the optimal imaging parameters to diagnose VRFs by using CBCT. In this study, 10 cases were done with the Morita unit and 19 (22 teeth) with the iCAT. This was based on availability of the unit and prescriptions submitted by the referring doctors. Hence, statistically significant differences in the diagnostic accuracy of the 2 imaging units could not be determined because of the limited sample size. Limited FoVs and higher resolution have been shown to be optimal for diagnostic situation requiring attention to small details, as in endodontics (26). Our pilot study clearly showed that in addition to the superior diagnostic performance of CBCT for VRF detection that was established, the sensitivity and specificity of data with smaller voxel sizes were higher. This might indicate that a limited FoV with the smallest isotropic acquisition voxel size might enhance detection of VRF on previously endodontically treated teeth. The iCAT used a larger FoV (single jaw) with a slightly lower spatial resolution as compared with the Accuitomo. Future studies evaluating the diagnostic outcome on the basis of variables such as the exposure parameters, FoV, voxel size, reconstruction parameters, dose, and post-processing techniques used are in order to attempt to further fine-tune such parameters for a specific diagnostic task. In addition, the effect of the training and experience of the observers on the diagnostic outcome will be evaluated. CBCT should be prescribed only for select, challenging cases in which information gleaned from conventional two-dimensional data precludes an accurate evaluation of the tooth of interest (27). The as low as reasonably achievable (ALARA) principle should always be considered when prescribing a CBCT study.

In conclusion, CBCT appears to be the imaging modality of choice for detection of VRFs in previously restored teeth when the most limited FoV and highest possible resolution are used, with interactive manipulation of the reformatted volume.

Acknowledgments

The authors deny any conflicts of interests related to this study.

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