CLINICAL RESEARCH

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In Vivo Detection of Subtle Vertical Root Fracture in Endodontically Treated Teeth by Cone-beam Computed Tomography

SIGNIFICANCE

Subtle VRFs are difficult to diagnose in clinic practice. The purpose of this article was to evaluate the diagnostic accuracy of CBCT imaging for subtle VRFs in endodontically treated teeth *in vivo* and to discuss the direct and indirect evidence for diagnosis.

ABSTRACT

Introduction: The purpose of this study was to evaluate the diagnostic accuracy of cone-beam computed tomographic (CBCT) imaging in the detection of subtle vertical root fractures (VRFs) in endodontically treated teeth *in vivo* and to discuss direct and indirect evidence for the diagnosis of subtle VRFs. **Methods:** Twenty-nine endodontically treated teeth with suspected VRFs from 29 patients were examined using CBCT imaging. CBCT images were scored based on evaluation of the fracture line and vertical buccopalatal (lingual) bone loss. VRF was diagnosed only when a definite fracture line was detected on CBCT images, and findings of periodontal exploration or surgical extraction were considered the gold standard. The diagnostic sensitivity, specificity, and accuracy were assessed. **Results:** Of the 29 teeth, 27 were positive and 2 were negative for VRF according to the gold standard. Sensitivity, specificity, and accuracy were 33.3%, 100%, and 37.9%, respectively, based on the direct finding of a fracture line on CBCT images. However, vertical buccopalatal (lingual) bone loss was found in 25 of 27 teeth with VRFs. **Conclusions:** Although the accuracy of CBCT imaging for the diagnosis of subtle VRFs in endodontically treated teeth *in vivo* was poor, vertical buccopalatal (lingual) bone loss is an important indirect sign for the diagnosis of VRFs, which can be found on CBCT images. *(J Endod 2019;45:856–862.)*

KEY WORDS

Cone-beam computed tomography; fracture line; vertical bone loss; vertical root factures

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Vertical root fracture (VRF) refers to the occurrence of a complete or incomplete longitudinal crack in a tooth root[1]. The fracture line often extends along the long axis from the root canal to the periodontal ligament, involving the tooth structure, pulp, and periodontal tissues[2]. Undetected VRFs may result in extensive bone loss and inappropriate treatment, leading to poor clinical outcomes. Hence, early definite diagnosis is imperative. However, because of the lack of specificity of clinical symptoms and limited information provided by conventional 2-dimensional periapical radiographs (PRs), definite diagnosis of VRFs is a challenge in clinical practice, particularly for subtle VRFs[1,3]. Therefore, we studied subtle VRFs in the present study, which were mostly incomplete, narrow, and hairline-like without separation of fractured fragments.

Direct radiographic diagnosis of VRFs is based on the presence of a hypodense (radiolucent) fracture line[4]. Such fracture lines are more clearly visible when the displacement of root segments is more extensive[5]. Although a direct sign of a fracture line could not be detected in PRs in most cases, the presence of a halo or J-type radiolucency around the root is an important indirect sign of suspected root fracture, and further examination (eg, surgical exploration) will be suggested[1].

In recent years, cone-beam computed tomographic (CBCT) imaging has been widely used for the detection of VRFs both *in vitro* and *in vivo*[5–8]. Although CBCT imaging allows avoidance of magnification, distortion, and anatomic superimposition, the ease of diagnosis varies according to the extent of the fracture. Several studies have been conducted to evaluate the diagnostic accuracy of CBCT imaging for VRFs. However, the detection of incomplete VRFs and hairline-like VRFs without obvious separation of fractured fragments can be more challenging compared with VRFs with extensive displacement of fractured fragments[5,9–11].

Moreover, there was a retrospective study reporting that 94% of teeth with VRFs had been endodontically treated[12,13]. Endodontic fillings can cause artifacts that seriously impair the quality of CBCT images and reduce diagnostic accuracy. Therefore, detecting fracture lines on CBCT images in endodontically treated teeth for definite diagnosis of VRFs, especially subtle VRFs, could be quite difficult. However, most of the previous studies were an *in vitro* assessment of using CBCT imaging to detect artificially induced VRFs in endodontically treated teeth, which were quite different from natural VRFs[14–16]. *In vivo* studies discussing the diagnostic accuracy of CBCT imaging for subtle VRFs was still deficient.

Thus, the aim of this study was to determine the *in vivo* diagnostic accuracy of CBCT images in detecting subtle VRFs in endodontically treated teeth. In the present study, CBCT images of 29 endodontically treated teeth with suspected VRFs were acquired; the fracture line and vertical alveolar bone loss were evaluated and scored. The purpose of this *in vivo* study was to evaluate the diagnostic accuracy of CBCT imaging based on a direct fracture line for subtle VRFs and to try to provide evidence of vertical periodontal bone loss as an indirect sign for the diagnosis of subtle VRFs.

MATERIALS AND METHODS

Clinical Data

CBCT images of 29 endodontically treated teeth from 29 patients were analyzed. Patients included those referred to our institution from September 2014 to September 2018 for definite diagnosis and treatment, including 9 men and 20 women (average age 55.2 [range: 22–77] years). According to clinical symptoms and history of root canal treatment (RCT), all tested teeth were suspected of VRFs. No fracture line was visible on PRs or panoramic radiographs, and hence, CBCT examinations were performed for further diagnosis. The inclusion criteria were as follows: slight occlusion discomfort, repeated swelling of the gums or sinus tracts after RCT; no displaced fracture fragments observed on CBCT images; and definite diagnosis by close follow-up.

This study was approved by the Ethics Committee of the Nanjing Stomatological Hospital, Medical School of Nanjing University.

Method

CBCT images were acquired using a NewTom VG scanner (QR srl, Verona, Italy) according to the manufacturer's instructions with a voxel size of 0.125 mm. CBCT images were analyzed using the built-in software NNT 5.3 (J Morita Manufacturing Corp, Kyoto, Japan) using a 29.7-inch RadiForce MX300 W (Eizo Nanao Corporation, Hakusan, Japan) screen with a resolution of 2560 × 1600 pixels. Coronal, sagittal, and axial planes at different root levels were displayed on the monitor.

Image Analysis and Scoring

The evaluation and score standard of CBCT images included the fracture line and type of bone loss. Diagnostic scoring was performed as follows:

1. A fracture line (complete or incomplete radiolucent [hypodense] line on axial images of the root in at least 2 consecutive slices)[14,15]: 0, no fracture line, and 1, a hypodense fracture line and no superimposition of streak artifacts secondary to the presence of root canal filling materials
2. Vertical buccopalatal (lingual) bone loss: 0, no bone loss and 1, vertical periodontal bone loss in either the buccal and/or palatal (lingual) side of the tooth root

Two observers (oral radiologists) assessed all images twice and determined the diagnostic scores independently. If a consensus could not be reached between the 2 examiners, a senior radiologist performed the final scoring. Before evaluation, calibration, including unified training on diagnostic standards of a fracture line and vertical bone loss, was performed. Scores of the fracture line and vertical bone loss were added together as the final score of the tooth, and, irrespective of the bone loss score, only teeth with a score of 1 for the fracture line were diagnosed as positive for VRFs. After 1 week, the observers assessed and scored all 29 cases again to analyze the intraexaminer agreement.

Radiographic diagnosis was confirmed by surgical extraction or periodontal exploration findings. The type of treatment was determined on the basis of clinical signs and symptoms, CBCT findings (a definite fracture line or severe bone loss), the prognosis, and patients' wishes. For teeth with a definite fracture lines, surgical extraction was performed. For teeth with bone loss but no definite fracture lines on CBCT images, periodontal exploration was suggested; meanwhile, the patients were informed of the prognosis and probability of extraction after exploration. For teeth without fracture lines and bone loss, periodontal exploration was performed.

For teeth intended for extraction, in order to exclude the possibility of an intraoperative fracture of the root, all teeth were extracted by a single experienced senior surgeon, and excessive rotational forces were avoided. All extracted teeth were carefully evaluated under a microscope (S100/OPMI pico; Carl Zeiss Meditec AG, Jena, Germany) to confirm the presence of a fracture line.

Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were assessed. Kappa analysis was used to assess inter- and intraexaminer agreement. Statistical analysis was conducted using SPSS 22.0 software (IBM SPSS Statistics Base Integrated Edition 22: IBM Corp, Armonk, NY).

RESULTS

The present study included no control group because we did not want to expose patients to unnecessary radiation with no clinical value[17]. CBCT diagnosis scores of all 29 teeth were as follows: 9 teeth scored 2, 17 teeth scored 1, and 3 teeth scored 0.

Nine teeth scored 2 could be definitely diagnosed VRFs and were extracted, proving they were fractured. Nine teeth scored 1 were periodontally explored, confirming narrow fracture lines on root surfaces, and then extracted. Six teeth scored 1 with extensive periodontal bone loss were extracted as a result of hopeless prognosis and patients' wishes, and fracture lines were observed. Two teeth scored 1 with severe periodontal and periapical bone loss were extracted in consideration of poor prognosis and patients' wishes, but a fracture line was only found on 1 tooth. Three teeth scored 0 were periodontally explored, and no fracture line was detected on 1 tooth. In the other 2 teeth, narrow fracture lines were confirmed but were retained and followed up.

In total, 27 teeth (12 premolars and 15 molars) were diagnosed with VRFs after surgical extraction or periodontal exploration, including 2 teeth scored 0 with no detected fracture lines or bone loss, 16 teeth scored 1 with undetected fracture lines but vertical buccopalatal (lingual) bone loss (Figs. 1*A–E* and 2*A–E*), and 9 teeth scored 2 with visualized fracture lines and bone loss (Fig. 3*A–E*). Moreover, vertical buccopalatal (lingual) bone loss adjacent to a fracture line could be detected in 25 of 27 cases with VRFs (Figs. 1–3).

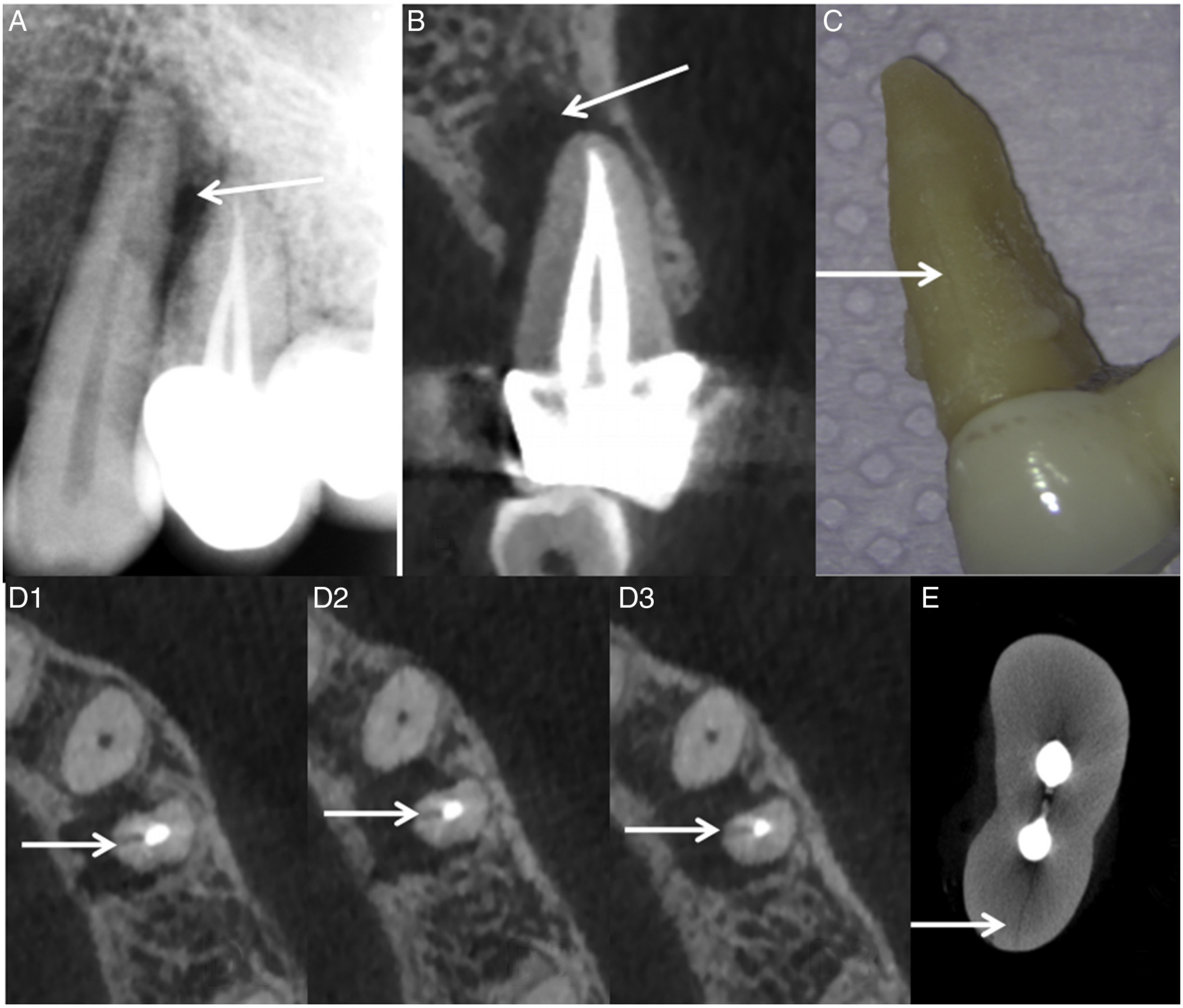

FIGURE 1 – An example of a tooth with a subtle incomplete fracture. (*A*) A PR taken after clinical examination showed that RCT was performed well. Lateral radiolucent areas were observed at the mesial aspect of the tooth. (*B*) A coronal reconstruction CBCT image along the axis of the root showed that vertical palatal alveolar bone loss had reached the apical region. (*C*) The extracted tooth showed the fracture line on the palatal side of the root. (*D*) *D1–D3* were axial images showing streak artifacts on the palatal side of the root. (*E*) A micro-CT image showed a subtle incomplete fracture line on the palatal side of the root *in vitro* with a voxel size of 0.02 mm.

The sensitivity, specificity, accuracy, PPV, and NPV of CBCT diagnosis of VRFs were 33.3%, 100%, 37.9%, 100%, and 10%, respectively. There was high inter- and intraexaminer agreement for the detection of vertical bone loss and substantial or moderate agreement for the detection of fracture lines (Table 1).

DISCUSSION

The diagnosis of VRFs can be extremely challenging in clinical practice. The recently widely used CBCT imaging allows dental practitioners to acquire 3-dimensional visualization of teeth with high spatial resolution and low radiation. Several studies have revealed improved accuracy of CBCT imaging in the diagnosis of tooth fractures compared with 2-dimensional PRs[6,8,18].

However, because of variations in the presentation of VRFs[19,20] and wide differences in CBCT scanning systems (different voxel sizes, radiation doses, detector performances, and postprocessing method)[16,21,22], the effectiveness of CBCT imaging in the diagnosis of VRFs cannot be guaranteed. Furthermore, the presence of root fillings or posts may complicate the visualization of fracture lines using CBCT imaging[23,24].

Based on the results of our study, the sensitivity, specificity, accuracy, PPV, and NPV of CBCT imaging in the diagnosis of VRFs were 33.3%, 100%, 37.9%, 100%, and 10%, respectively. The sensitivity and NPV are lower compared with previous studies, wherein the sensitivity values varied from 84% (0.64–0.95) to 100% (0.83–1.00), the specificity values varied from 64% (0.35–0.87) to 100% (0.03–1.00), PPV ranged from 71% (0.51–0.87) to 100% (0.63–1.00), and NPV ranged from 50% (0.01–0.99) to 100% (0.84–1.00)[25]. Chavda et al determined the *in vivo* diagnostic

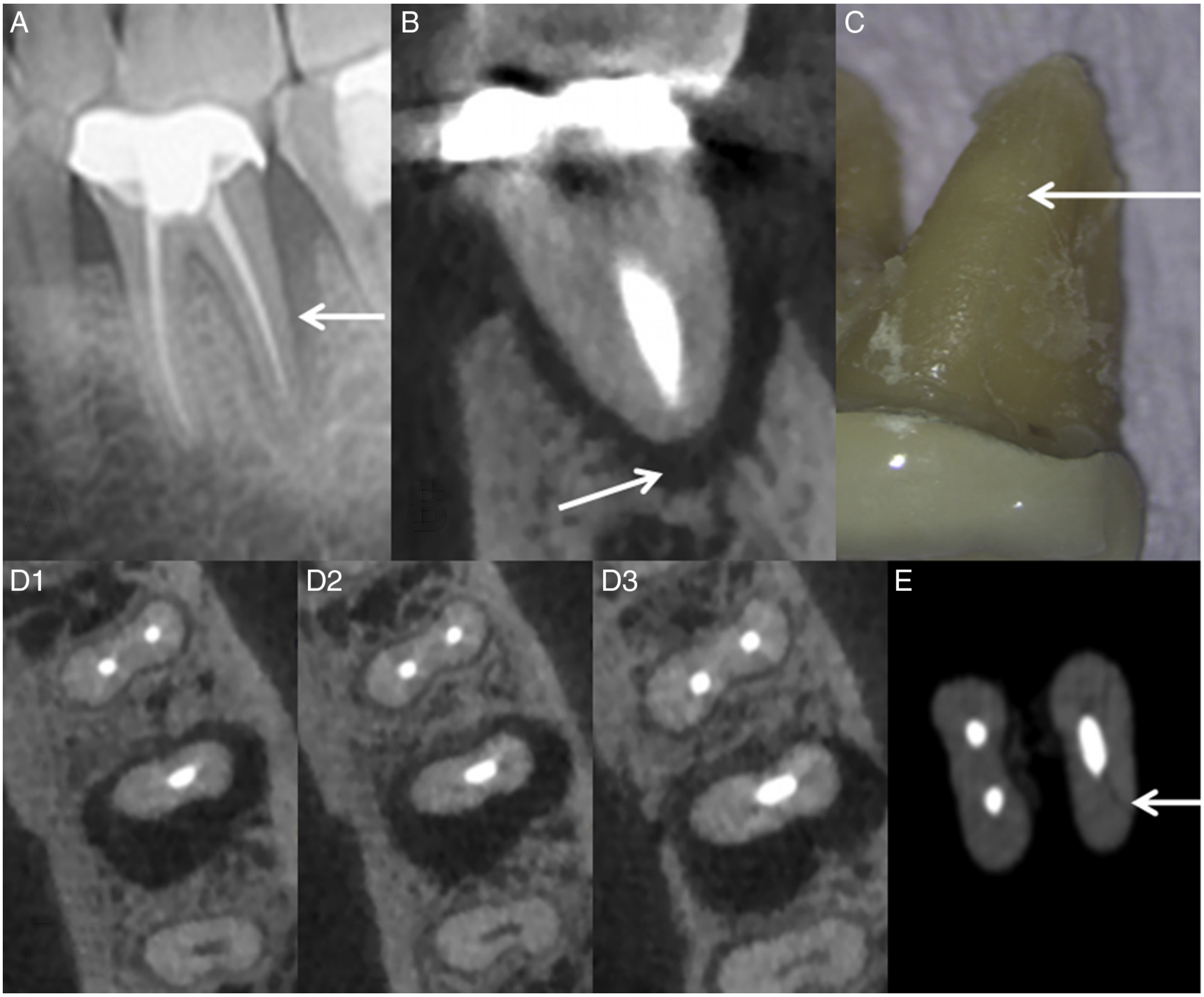

FIGURE 2 – An example of a tooth with a complete fracture. (*A*) A panoramic radiograph showed that RCT was performed well. Radiolucent areas were observed around the distal root. (*B*) Coronal reconstruction along the axis of the distal root showed vertical buccal and lingual alveolar bone loss around the distal root that had reached the apical region. (*C*) The extracted tooth showed the fracture line. (*D*) *D1–D3* were axial images showing alveolar bone loss but no fracture line. (*E*) An *in vitro* micro-CT image showed a complete fracture line on the distal root with a voxel size of 0.02 mm.

accuracy of CBCT imaging in the detection of VRFs[20] and reported poor sensitivity (0.27) but high specificity (0.83), which is more consistent with our findings. It is well-known that the ease of diagnosis varies according to the extent of the fracture[5,10,11]. In this study, we studied narrow, subtle VRFs without obvious separation of fractured fragments (Figs. 1*E*, 2*E*, and 3*E*), resulting in lower sensitivity. *In vitro* studies support the use of CBCT imaging for the detection of VRFs in teeth[26,27] by artificially creating VRFs, different from the "natural" ones; the initial natural fracture lines *in vivo* could be quite subtle. Ozer[26] created fractures of known width (<0.2, 0.2, and 0.4 mm) in root-filled teeth and reported that CBCT imaging was more accurate in detecting 0.2-mm (70%) and 0.4-mm (90%) fractures than <0.2 mm.

Detection accuracy between *in vitro* and *in vivo* conditions varies widely[6,16]. *In vitro* findings do not incorporate patient factors, including the effect of the surrounding tissues (eg, soft tissues and alveolar tissues) that could influence the quality of CBCT images[28] or the possibility of motion artifacts during scanning[24] that may obscure the putative fracture plane. Moreover, the principles of "as low as reasonably achievable" must be upheld in CBCT examinations; accordingly, the decreased radiation dose of *in vivo* scanning also contributes to poor image quality and reduced accuracy of the detection of fracture lines[29].

Radiographic diagnosis of VRFs is based on the presence of a hypodense (radiolucent) fracture line[4]. In fact, VRFs are commonly observed in teeth after RCT. However, the artifacts of dense root canal fillings obviously interfere with radiographic interpretation of CBCT images (Fig. 1*D*), which can reduce diagnostic accuracy[23,30]. Therefore, in the present study, although 27 teeth had VRFs, facture lines could be definitely detected in 9 teeth alone (Fig. 3*D*). Similarly, Corbella et al[21], Talwar et al[19], and Salineiro et al[30] reported significantly reduced sensitivity of CBCT imaging attributed to streaking artifacts of root canal fillings.

Certain clinical signs frequently correlate with VRFs, such as multiple sinus

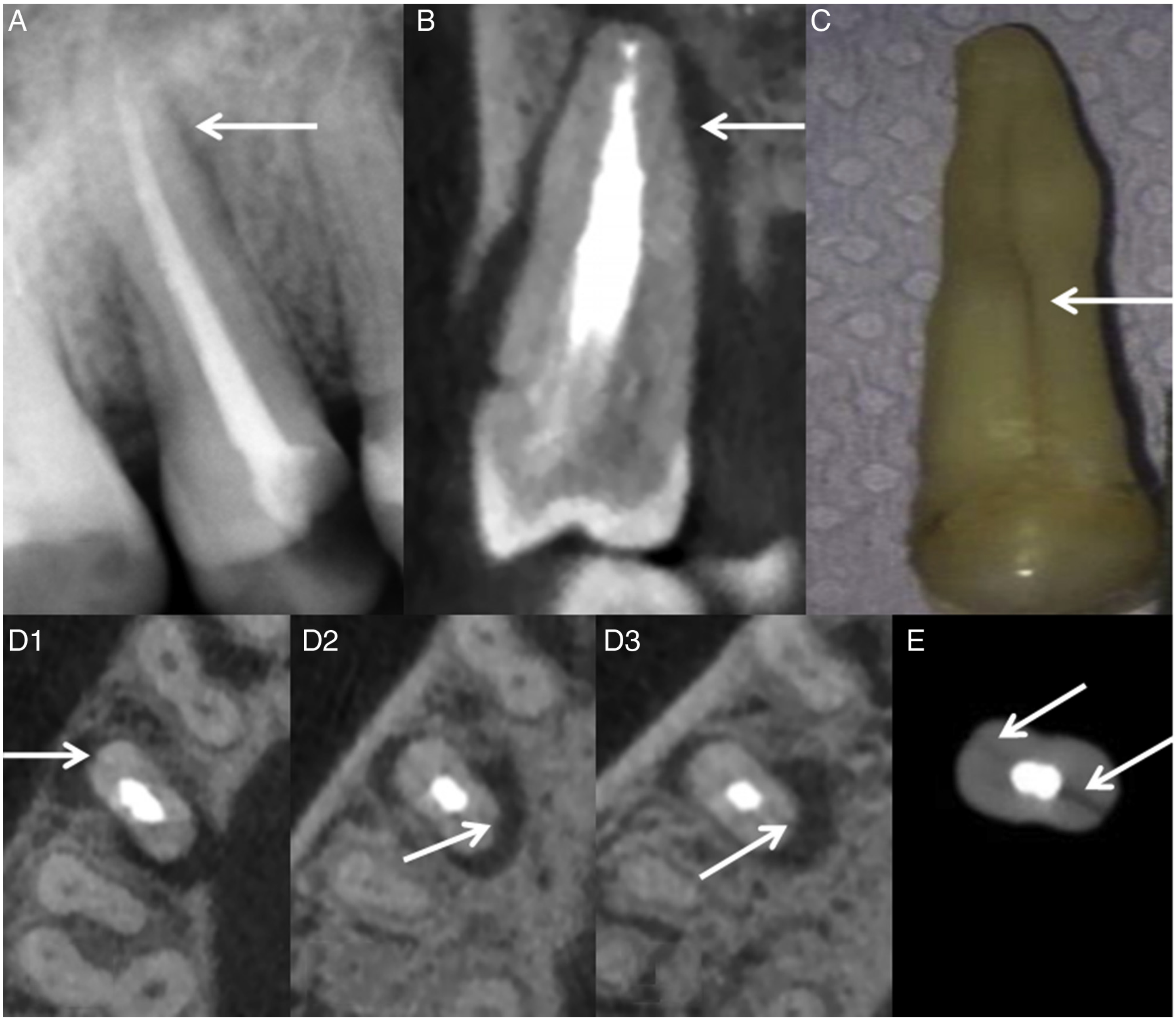

FIGURE 3 – An example of a tooth with subtle fracture lines on both the buccal and palatal sides. (*A*) A PR showed that RCT was performed well, and thickened periodontal ligament was observed. (*B*) A coronal reconstruction CBCT image along the axis of the root showed that the buccal and palatal alveolar bone loss had reached the apical region. (*C*) The extracted tooth showed the fracture line. (*D*) *D1–D3* were axial images showing subtle hypodense fracture lines on both the buccal and palatal sides of the root surfaces. (*E*) An *in vitro* CBCT image confirmed fracture lines on the root with a voxel size of 0.125 mm.

tracts and deep, narrow periodontal osseous defects in an isolated tooth[12,31]. With the development of a fracture, the bone destructed along the fracture lines forms a drop shadow or a "periodontal ligament"–like bone defect with widened periodontal space and bone loss. In addition, severe fractures can cause bone loss or diffuse loss of alveolar bone around affected teeth. The corresponding presentation in PRs is a halo or J-type radiolucency around the tooth with suspected VRF, and this sign has been indicated as an important indirect sign of root fracture on PRs[31–33].

TABLE 1 - The Reliability of the 2 Examiners with Regard to Vertical Root Fracture Detection

Reliability of examiners	Fracture line	Bone loss
Interexaminer agreement	0.631	1
Intraexaminer agreement		
Examiner 1	0.696	1
Examiner 2	0.563	1

Among the 27 teeth diagnosed with VRFs, 25 teeth had vertical bone loss adjacent to the fracture lines on CBCT images. Vertical periodontal bone loss has been regarded as an important indirect auxiliary diagnostic sign for VRFs[1,34]. Although the diagnostic accuracy of CBCT imaging for subtle VRFs after RCT was disappointing, it is worth mentioning that vertical bone loss, as noted on CBCT imaging, is an important indirect sign. Moreover, buccal (labial) and palatal (lingual) bone loss could not be detected on PRs but were 3-dimensionally identified on CBCT images.

CONCLUSION

The diagnostic accuracy of CBCT imaging for VRFs remains controversial. Based solely on a fracture line, sensitivity and accuracy was poor in the diagnosis of subtle VRFs in endodontically treated teeth in this study. However, vertical buccopalatal (lingual) bone loss was found in most VRF teeth and therefore could be an important indirect sign for the diagnosis of VRFs. Furthermore, this type of bone loss could be indicated on CBCT images.

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Lei Zhang and Tiemei Wang contributed equally to this study.

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

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