Diagnosis and Treatment of Endodontically Treated Teeth with Vertical Root Fracture: Three Case Reports with Two-year Follow-up

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Abstract

Introduction: Vertical root fracture (VRF) is an important threat to the tooth's prognosis during and after root canal treatment. Often the detection of these fractures occurs years later by using conventional periapical radiographs. However, recent studies have addressed the benefits of computed tomography to diagnose these problems earlier. Accurately diagnosed VRFs have been treated by extraction of teeth, with minimal damage to the periodontal ligament, extraoral bonding of fractured segments with an adhesive resin cement, and intentional replantation of teeth after reconstruction. **Methods:** The 3 case reports presented here describe the diagnosis and treatment of vertically fractured teeth that had been previously treated endodontically. Cone-beam computed tomography (CBCT) was used for diagnostic imaging to detect VRFs. Vertically fractured roots were carefully extracted and extraorally treated by using a self-etching dual-cure adhesive resin cement, and intentional replantations were performed after reconstruction. **Results:** After a mean follow-up period of 2 years, the teeth were asymptomatic. There was no clinical ankylosis, and diagnosis by using CBCT scans showed reduced periapical radiolucency. **Conclusions:** Extraoral bonding of fractured segments and intentional replantation of teeth after reconstruction provide an alternative treatment to extraction, especially for anterior teeth. Computed tomography–assisted VRF diagnosis is helpful in detecting fractures; however, higher-resolution tomography units providing better image quality would be a better choice for improved visualization of these fractures. *(J Endod 2011;37:97–102)*

Key Words

Cone-beam computed tomography, dual-cure resin, intentional replantation, reattachment, vertical root fracture

A vertical root fracture (VRF) manifests as a complete or incomplete fracture line extending obliquely or longitudinally through the enamel and dentin of an endodontically treated root. VRFs usually result in extraction of the affected tooth (1). Major iatrogenic and pathologic risk factors for VRFs include excessive root canal preparation, overzealous lateral and vertical compaction forces during root canal filling, moisture loss in pulpless teeth, overpreparation of post space, excessive pressure during post placement, and compromised tooth integrity as a result of large carious lesions or trauma (2). Whereas a multi-rooted tooth with VRF can be conserved by resecting the involved root, a single-rooted tooth usually has a poor prognosis, leading to extraction in 11%–20% of cases (3).

Although several methods have been used to preserve vertically fractured teeth, no specific treatment modality has been established (4–9). Successful short-term (5,6) and long-term (8,9) outcomes have been reported for VRF reconstruction with adhesive resin cement. Long-term clinical results suggest an alternative approach to extraction: the extraoral bonding of fractured segments with an adhesive resin cement and intentional replantation of teeth after reconstruction (8, 9).

The diagnosis of VRF can be problematic, and it often requires prediction rather than definitive identification (10). Conventional periapical (PA) radiographs taken from different angles do not provide precise images of these fractures (11). The location and size of the defect cannot always be objectively assessed without extraction or simultaneous mucoperiosteal flap surgery. VRFs frequently escape detection during treatment, which might lead to bone loss, pain, and malfunction of the involved area (12). Thus, early identification of VRFs is important. Recent studies have found that cone-beam computed tomography (CBCT) is more accurate than conventional PA radiography for the detection of longitudinal root fractures, because its additional imaging capabilities permit direct visualization of fracture lines (10, 13–16).

The present case series describes an alternative approach to the treatment of teeth with VRFs that have been detected by using CBCT and addresses the impact of accurate CBCT-assisted diagnoses on the predictability of successful outcomes.

Procedures

The same diagnosis and treatment protocols were applied to all cases referred to the School of Dentistry, Dicle University, Diyarbakir, Turkey. CBCT scans were taken of each patient by using 0.2-mm voxel size, 6-cm field of view (FoV), 120 kV, and 5 mA. The images were evaluated by 2 endodontists trained to read CBCTs. VRFs were assessed with axial- and sagittal-plane images. Fractured teeth were classified into 2 groups according to the type (hairline versus separated) and location of the fracture (Table 1). Hairline-like VRFs without separation of the fractured fragments were identified in 2

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TABLE 1. Treatment Modalities of Intentionally Replanted Teeth

Case no.	Tooth no.	VRF type	Reconstruction method	Time (min)
1	10	Complete VRF	Total adhesion	12
	11	Hairline-like VRF	Shallow sealing	16
2	22	Hairline-like VRF	Shallow sealing	18
3	6	Complete VRF	Total adhesion	24

Complete VRF, vertically fractured fragments are totally separated through entire root; Hairline-like VRF, there is no separation between fractured fragments; Total adhesion, VRF fragments were adhered to each other with resin cement through entire root; Shallow sealing, hairline-like VRF was prepared shallowly and resin cement was placed through VRF initially; Time, operation time including tooth extraction, reconstruction, and intentional replantation.

cases (Figs. 1*E*, Fig. 2*B*). Two cases had VRFs through the entire root with separated fragments (Figs. 1*B*, 3*B*).

All patients received preoperative oral hygiene instruction. The details, possible benefits, and risks of the procedure were explained to the patients, and written consent was obtained.

The treatment plan for VRF consisted of the following steps: (1) extraction of affected teeth while avoiding periodontal damage, (2) bonding of the separated segments with a self-etching dual-cure adhesive resin cement (Panavia F 2.0; Kuraray, Osaka, Japan), and (3) intentional replantation of the reconstructed teeth.

The following surgical protocol was applied to all patients. (1) Local anesthesia by using a solution of 2% articaine with 1:1000 epinephrine (Ultracain DS; Aventis İlaç A.Ş, İstanbul, Turkey) was performed. (2) A full-thickness mucoperiosteal flap was elevated. (3) The supra-alveolar fibers were circumferentially dissected. (4) The tooth was gently extracted to protect the periodontium. (5) Each extracted tooth was immediately immersed in saline solution (0.9% isotonic NaCl; İE Ulagay İlaç Sanayi, İstanbul, Turkey). (6) The socket walls adjacent to the fracture region were curetted and irrigated with saline solution to remove inflamed tissue.

The fracture lines of the 2 hairline-like VRFs were prepared as a shallow preparation, and each fracture line was sealed with self-etching dual-cured adhesive resin cement. Minimal sealant was applied to avoid covering the periodontal ligament. VRFs through the entire root were treated by removing the root-filling material with a sharp scalpel (Fig. 3*D*) and irrigating with saline. Granulation tissue was removed from the root fracture sites, which were then dried and bonded with self-etching dual-cured adhesive resin cement (Fig. 3*E*). The root surfaces were treated with tetracycline for 30 seconds to enhance periodontal ligament cell attachment (17). The reconstructed teeth were then replanted in their original positions (5, 6, 8, 9).

The extraoral procedures required 16–28 minutes, depending on the number of treated teeth. The teeth were kept in gauze moistened with saline during curing. After fragment attachment, the resin was cured for 20 seconds at 400–450 mW with a light-curing unit (Degulux; Degussa AG, Frankfurt, Germany).

The patients were prescribed a chlorhexidine digluconate mouth rinse and 3× 500 mg amoxicillin plus 2× 550 mg naproxen daily for 1 week. Sutures (3.0 silk suture; Boz, Ankara, Turkey) were removed 7 days after surgery.

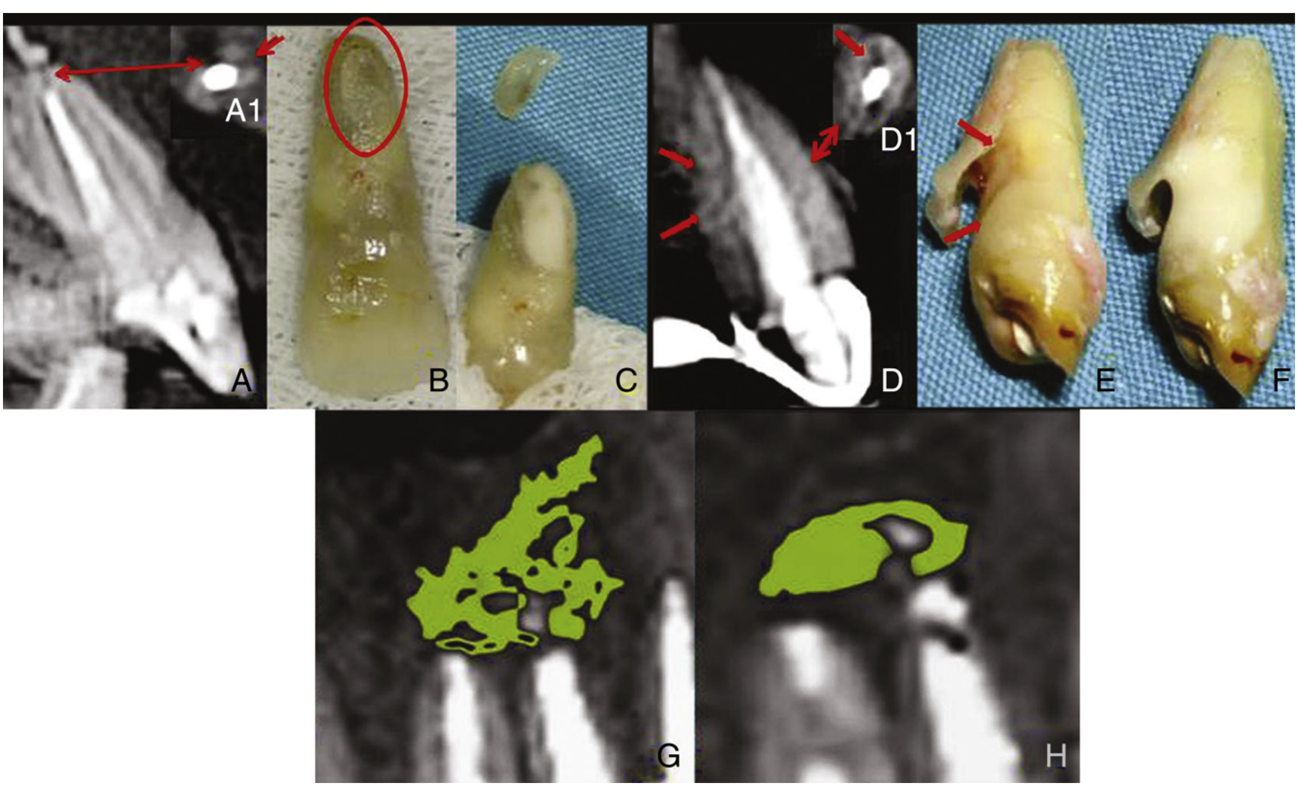

Figure 1. (*A*) Image from sagittal plane shows crack line apically on left maxillary lateral incisor. (*A1*) Image from axial plane is taken through the apical third of the root and shows signs of cracks (arrow). (*B*) Extracted tooth on moist gauze. Note the fracture line elliptically surrounding the apical third of the root. (*C*) Separable fractured fragments were adhered to each other by using dual-cure cement. (*D*) Image from sagittal plane shows crack lines on left maxillary canine. There are cracks on the lingual surface (arrows). (*D1*) Arrows showing the cracks on axial plane. (*E*) An incomplete hairline-like crack was detected visually. (*F*) After a shallow preparation, dual-cure resin was placed through the defect. (*G*) PA radiolucency at the apical region. Image from coronal plane shows the affected area in bone before treatment. (*H*) PA radiolucency is reduced at end of 24 months after intentional replantation.

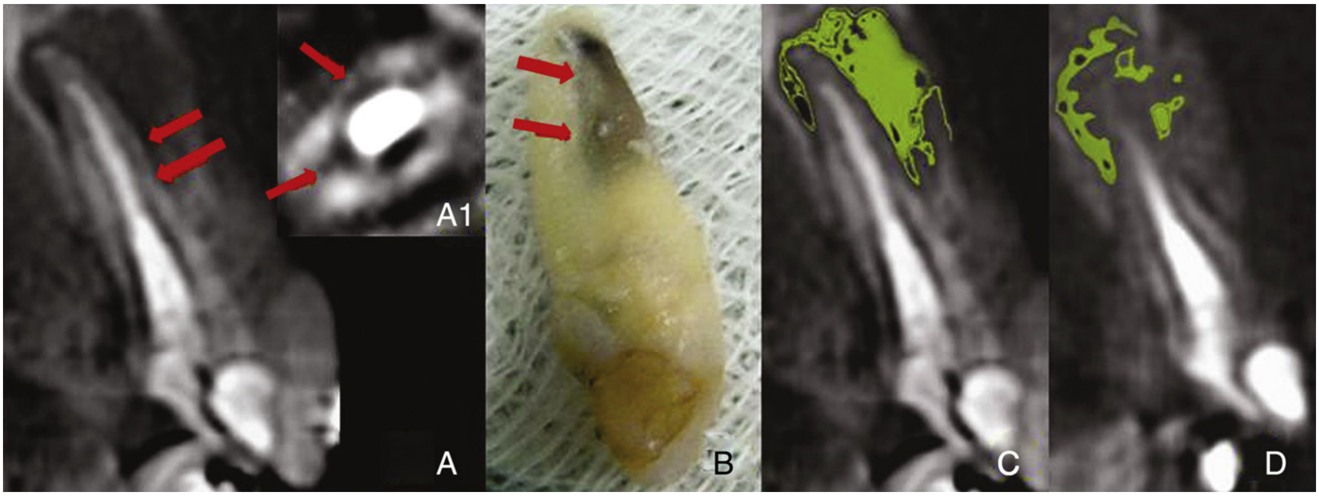

Figure 2. (*A*) Image of left maxillary lateral incisor from sagittal plane representing large bone defect destroying the cancellous bone. (*A1*) Arrows show signs of VRF on image taken axially. (*B*) On extracted tooth with hairline-like vertical fracture, fracture lines were visible with staining caused by root canal filling materials. (*C*) Preoperative image on sagittal plane points out a large lesion through apical and middle thirds of the root. (*D*) Size and volume of lesion were clearly reduced at end of 24 months.

Six-monthly clinical examinations were conducted to evaluate tooth mobility and sensitivity to percussion. The percussion tone was evaluated and compared with adjacent noninjured teeth. All affected teeth were restored with full-cast crowns 2–6 months after reconstruction and intentional replantation. CBCT scans were performed 2 years after surgery.

Treatment outcomes were classified as successful or failed at 2 years. Clinical success was defined by lack of sensitivity to percussion, percussion tone that did not differ from the healthy adjacent teeth, and mobility within normal limits at 6 months after reconstruction and intentional replantation. In addition, reduction in periapical radiolucency was evaluated. Failure was defined as clinical conditions that did not meet the requirements for success and/or increased discomfort of the patient.

Case 1

A 36-year-old man with no systemic health problems was referred to our practice in March 2008. He complained of chronic dull pain in the left anterior maxilla. Clinical examination revealed large composite resin restorations in the maxillary incisors and canines. The periodontal pocketing showed an average depth of 3 mm, and the affected teeth exhibited no mobility. Radiographic examination and the patient's anamnesis indicated that the left central and lateral incisors and canine had undergone root canal treatment 3 years before his referral. An apical surgery had been performed subsequent to this treatment for unknown reasons. Because of failed healing, the root canals had been retreated 2 years later.

Given the patient's history of poor treatment outcomes, we did not attempt to re-treat the root canals. Axial and sagittal CBCT scans showed VRFs on the left maxillary lateral incisor (Fig. 1*A*,*A1*) and an incomplete hairline-like VRF (Fig. 1*D*, *D1*, *E*) on the left maxillary canine, varying in size and location. The patient underwent surgery as described above. Six months later, teeth were asymptomatic clinically. The treatment outcomes of the 2 teeth were classified as successful 2 years after surgery, with reduced PA radiolucency (Fig. 1*H*).

Case 2

A 25-year-old woman presented in January 2008 after 2 years of orthodontic treatment. She complained of mild pain in her maxillary left lateral incisor during chewing, which increased in severity

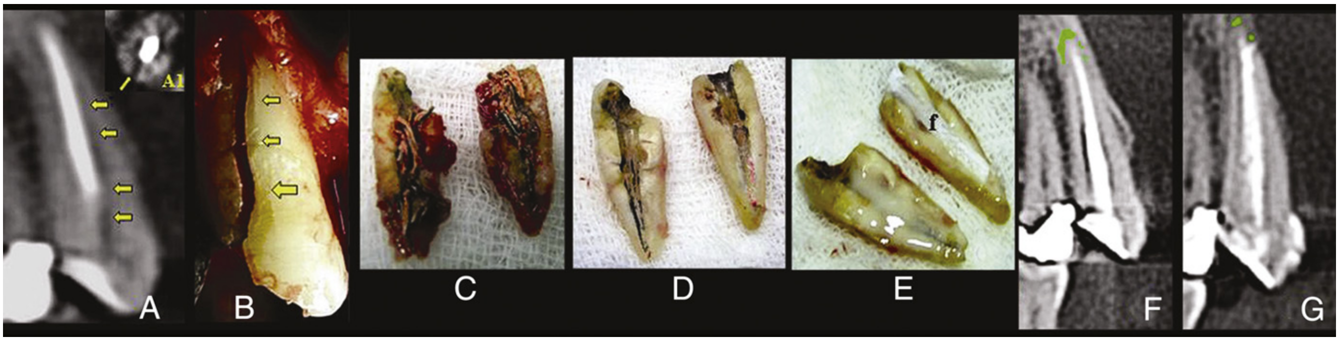

Figure 3. (*A*) Image of right maxillary canine insicor from sagittal plane shows signs of VRF through entire root with definite radiolucent line along the root canal filling. (*A1*) Axial image shows definite radiolucent tracks indicating VRF. (*B*) Preoperative photograph of affected tooth after mucoperiosteal flap elevation. Granulation tissue is evident between the fractured segments. (*C*) Root canal obturation material is in contact with granulation tissue. Separated segments were kept in moist gauze to prevent dehydration. (*D*) Root canal filling is removed through entire root. (*E*) Dual-cure resin was placed on the separated segments, and a polyethylene fiber (f) was inserted for increased retention of the coronal restoration. (*F*) Preoperative CBCT image from sagittal view shows presence of lesion apically. (*G*) Postoperative CBCT image from the same plane reveals evidence of healing at 24 months with reduced PA radioluceny.

immediately after each orthodontic treatment session. A root canal had been performed on the tooth 2 years previously. CBCT examination detected a large root canal filling with a 2-cm^2 PA lesion (Fig. 2C). Clinical examination showed that the buccal and palatal periodontal pockets averaged 5 mm in depth. CBCT scans revealed a hairline-like VRF on the apical and middle thirds of the root (Fig. 2A, A1).

The affected tooth was debonded, and orthodontic treatment of the maxillary left incisors was terminated. Because the affected area was larger than those of the other cases presented here, graft material (Puros Cancellous Particles, 0.5 cc; Zimmer Dental, Carlsbad, CA) was placed into the bone defect during surgery to enhance bone formation.

The patient's final examination was performed 8 months after surgery. Periodontal probing had not been performed before this examination to allow regeneration of the periodontal tissues. The tooth was asymptomatic, with no clinical signs of failure. No refracture was observed clinically, and the tooth remained functional, exhibiting physiologic mobility. PA radiolucency was reduced at the end of 2 years (Fig. 2D).The outcome was thus assessed to be successful.

Case 3

A 32-year-old man was referred to us in February 2008, complaining of draining pus and chronic dull pain in the right anterior region of the maxilla. Clinical examination revealed a separable distal fracture on the maxillary right canine (Fig. 3B), and CBCT images confirmed the diagnosis of VRF (Fig. 3A, A1). The patient underwent surgery as described above. However, because of tooth structure loss coronally, a polyethylene fiber (Ribbond; Ribbond Inc, Seattle, WA) was adhered on the root dentin to form a post for retention of a planned crown restoration (Fig. 3E). At 2 years after reconstruction and intentional replantation, the tooth was asymptomatic, with physiologic mobility. PA radiolucency was reduced (Fig. 3G). The treatment outcome was thus deemed to be successful.

Discussion

A VRF extends to the periodontal ligament, and soft tissue grows into the fracture. Separations between fractured fragments increase and resorption areas enlarge over time, negatively affecting the possibility of further treatment in the affected area (12). Rapid diagnosis of a VRF is required to prevent additional bone loss that will further impede reconstruction.

The current available methods to detect VRFs are illumination, x-rays, periodontal probing, staining, surgical exploration, bite tests, direct visualization of the fracture, operative-microscope examination, and CBCT scanning, which has been accepted as an innovative diagnostic tool (18). Because of the exposure of harmful ionized radiation during tomographic scans, alternative diagnostic imaging systems are being tested. Optical coherence tomography is another high-resolution imaging system with infrared light that reflects off internal structures within biological tissues (18, 19); however, this system is designed only for medical purposes and is not yet suitable for dental use (18).

Recent studies have shown that CBCT scanning can successfully detect these problems (10, 13–16). On the basis of these studies, CBCT scans were used in the present cases to diagnose VRFs. Extraoral VRF treatment that included resin cement bonding and intentional replantation was then performed. This alternative treatment method is particularly appropriate for anterior teeth (5, 6, 8, 9). Hayashi et al (8) reported no failure in vertically fractured incisors treated with this method, although failures did occur in premolars and molars. The authors suggested that the posterior teeth were negatively affected by strong occlusal forces. The morphology and location of anterior teeth also facilitate the maintenance of gingival health, a further reason for positive outcomes after VRF treatment. Öztürk and Çelik Ünal (9) reported a successful 4-year outcome for a vertically fractured incisor. This tooth was also intentionally replanted in the manner described here and supported by a bioresorbable membrane to promote bone filling. Arikan et al (6) reported a successful 18-month outcome for VRF treatment and recommended the procedure described in this article. They also showed that the use of a dual-curing material shortened extraoral working time and preserved the vitality of the periodontal ligament, thereby increasing the probability of long-term replantation success. On the basis of the good prognoses reported in these studies and the suggestions they offered, the present cases were referred for intentional replantation after reconstruction with a self-etching, dual-cure adhesive resin.

Achieving high bond strength throughout an entire root canal is quite difficult when using modern dentin bonding systems (20). Hayashi et al (21) addressed the imperfect curing of the light-cured adhesives at the apical portions, questioning previously given reasons for reduced bond strengths. They reported that chemical-cured total-etch adhesive materials had stable bonding performances in an entire post space and were advantageous in post-core restorations. Recent studies have reported that the use of 4-META/MMA-TBB resin, a self-cure adhesive resin cement, leads to successful VRF reconstruction outcomes (5). Given the difficulties of polymerization control with this resin, however, dual-cure adhesive resin cements are preferable. These cements achieve controlled polymerization, are easy to apply, have short curing times (6, 9), and produce successful outcomes. Andreasen et al (22) treated the roots of 2 incisors with apicoectomy and a retrograde dentin-bonded composite filling, concluding that the tissue accepted the composite as a base for cementogenesis. They cautioned against covering the periodontal ligament to allow for better proliferation of periodontal ligament cells when the resected root end was covered. In the present cases, we used shallow preparation cavities through the hairline-like VRFs and minimal resin on the root surface. Healthy cementum on the root surface and periodontal membrane vitality are important factors in preventing ankylosis (9, 22). Solutions such as citric acid, tetracycline, and ethylenediaminetetraacetic acid have been advocated for root surface modification because they remove the smear layer to produce a surface that is conducive to cellular adhesion and growth (23). A 30-second application of tetracycline has been reported to successfully remove the smear layer, leaving clean and open tubules (17). Tetracycline was thus applied to all root surfaces in the present cases to enhance periodontal ligament fiber attachment.

Ankylosis represents fusion of the alveolar bone and root surface and can be demonstrated 2 weeks after replantation. Clinically, the ankylosed tooth is immobile and percussion tone is high, differing clearly from the adjacent noninjured teeth (22). The percussion test can often reveal replacement resorption in its initial phases before it can be diagnosed radiographically (24). Andersson et al (25) showed that ankylotic areas of teeth were evident radiographically when the ankylosis was located on the proximal surfaces of the root, but they were not evident when the ankylosis occurred on the lingual or labial surfaces. Radiographic examination is considered to be of limited value in the early detection of ankylosis because of the 2-dimensional nature of the image (26). The initial location of ankylosis is often on the labial and lingual root surfaces, complicating radiographic detection (25, 26).

Thus, during our controls for 6 months before the placement of temporary crowns, the mobility and percussion sound were clinically evaluated. All subjected teeth were mobile within normal limits, and the percussion tone did not differ from the healthy adjacent teeth.

The absence of ankylosis for a mean period of 1 year suggests a good long-term prognosis. All teeth should be monitored for a longer period, however, because ankylosis might occur after 5–10 years (24). Because the earliest signs of PA pathology are discontinuity in the lamina dura and widening of the periodontal ligament space, it is desirable that the resolution of the CBCT imaging system used does not exceed 200 μm (0.020 mm), which is the average width of the periodontal ligament space (27). Thus, the i-CAT used in the present cases was unable to exactly evaluate this thickness because it provided a resolution of 0.200 mm, which was within the limits of the parameters used. Thus, ankylosis was evaluated only by clinical tests such as the evaluation of tooth mobility and percussion tone.

There are variations among different CBCT units in their abilities to detect VRFs as a result of the size and shape of detectors, FoVs used, and voxel sizes selected (14). On the basis of FoV selections, CBCTs are categorized as the following: (1) small volume used to scan a few teeth or one jaw; (2) medium volume, involving both jaws, the maxillary sinus, and part of the nose; and (3) large volume, covering the entire maxillofacial region (14, 28). FoV selection is directly related to voxel size and influences spatial and contrast resolution. Larger FoVs provide less resolution and contrast in comparison with small FoVs, which directly influences the visibility of structures (27). Generally, the smaller the scan volume, the higher is the spatial resolution of the image. In our cases, Next-Generation i-CAT (medium FoV) was used with a 0.2-mm voxel size, instead of a 0.125-mm voxel size, to decrease exposure to ionizing radiation, which unfortunately reduced the quality of images. The images (Figs. 1*A*, *A1*, *D*, *D1*, 2*A*, *A1*, 3*A*, *A1*) were unable to clearly demonstrate cracks as a result of the decreased resolution, which is an obvious limitation, and the treatments were performed before some of the newer CBCT units were available.

Newer CBCT machines are reported to have higher resolution (better image quality) with reduced radiation doses (14, 27). Scarfe et al (27) reported that the Kodak 9000 3D (Kodak Dental Systems, Atlanta, GA) was the CBCT unit with the highest resolution and the smallest FoV (0.076 mm), which involved patient radiation exposure varying from 0.4–2.7 digital panoramic equivalents, depending on the part of the mouth studied. Similarly, the 3D Accuitomo (J. Morita Corp, Kyoto, Japan) has been reported to provide a minimum voxel size of 0.08 mm with similar exposure doses (27). Small FoV scanners have the advantages of reduced costs and limited volume examination properties for endodontic applications, with decreased radiation doses, compared with medium FoV scanners.

Scarfe et al (27) evaluated the effect of voxel size on resolution and reported higher accuracy for 0.12-mm versus 0.4-mm voxel size, suggesting that if CBCT is to be used, then resolutions of the order of 0.12 mm or less are optimal. When Wenzel et al (15) evaluated the diagnostic accuracy of CBCT and a photostimulable storage phosphor plate system to detect VRFs, they used an i-CAT scanner with 0.125-mm and 0.25-mm voxel sizes. Higher accuracy was reported with the smaller voxel sizes (0.125-mm versus 0.4-mm voxels), and high-resolution scanning was recommended in cases of suspected VRF that could not be visualized in PA images.

CBCT scans precisely depicted the intraoral characteristics of the VRFs in these cases. VRFs are defined to extend longitudinally onto the root surface, and it is reasonable that a horizontal cross section perpendicular to the VRF would provide the best detection (14). As previously reported by Hassan et al (14), axial slices were more accurate than coronal and sagittal slices in detecting VRF. Thus, we predominantly used axial-plane images to diagnose VRFs (Figs. 1*A1*, *E1*, 2*A1*, 3*A1*), confirming the investigation by Hassan et al of slice orientation and scanner characteristics for accurate VRF diagnosis. Sagittal-plane images were useful for determining the extent and direction of each fracture line (Figs. 1*A*, *E*, 2*A*, 3*A*). The teeth were classified into 3 groups according to the extent of the fracture, as previously described by Hayashi et al (8) (Table 1). The middle and apical fracture group included 2 teeth with hairline-like VRFs (Figs. 1*E*, 2*B*). A fracture in the middle third of one tooth extended across one third to two thirds of the cervical portion toward the apex. An apical fracture on one tooth extended across more than one third of the apical portion. Two teeth exhibited VRFs through the entire root, with separated fragments (Figs. 1*C*, 3*B*).

The clinical symptoms and radiographic signs are not completely pathognomonic, although dual sinus tracts or sinus tract–like pockets on opposite sides of a root are considered almost pathognomonic for a VRF (1). CBCT provides enhanced and accurate information for the diagnosis of root fractures, thereby constituting an excellent alternative for diagnosis in dental practice. However, clinical signs and symptoms are fundamental and very important for the diagnosis of fractures, and one must consider the signs and symptoms too (13).

Conclusions

(1) This study was limited to the CBCT systems that were accessible when this study was conducted. New models with different technical specifications appear on the market each year from the same or other manufacturers. Scanners with smaller FoVs with higher resolutions would be advisable for use in detecting VRFs and in the follow-up period.
(2) Early and accurate diagnosis of all VRF types is important in preventing buccal and/or lingual bone plate and cancellous bone destruction. CBCT imaging allows the clinician to accurately detect these problems and inform the patient about alternative treatments.
(3) Bonding the separated fragments of VRFs extraorally and intentional replantation of the reconstructed tooth are an innovative method that provides an alternative to tooth extraction, especially for anterior teeth.
(4) Further long-term studies of treatment outcomes are necessary to confirm the effectiveness of this protocol.

Acknowledgments

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

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