Diagnosis of Vertical Root Fractures with Optical Coherence Tomography

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Abstract

The purpose of this experiment was to evaluate the ability of optical coherence tomography (OCT) to image vertical root fractures (VRFs). Twenty-five mandibular premolars were prepared to size 50. Five teeth served as controls. Group 1 (n = 10) was treated with ethylenediaminetetraacetic acid and ultrasonic irrigation, whereas group 2 (n = 10) received no further treatments. Teeth from groups 1 and 2 were fractured, and the presence of a fracture line was demonstrated microscopically. Control group teeth were not subjected to any force. Teeth were pooled and scanned with an OCT fiber. The resulting video files were blindly interpreted by 2 observers .No fractures were detected in the control teeth. The overall sensitivity for detection of VRFs with OCT was 93% for group 1 and 84% group 2, whereas the specificity was 95% for group 1 and 96% for group 2. OCT is a promising nondestructive imaging method for the diagnosis of VRFs. *(J Endod 2008;34:739–742)*

Key Words

Imaging, optical coherence tomography, sensitivity, specificity, vertical root fracture

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Vertical root fracture (VRF) is a considerable threat to the tooth's prognosis during and after root canal treatment (1). VRF presents a challenge to the clinician in that the diagnosis is often difficult and is based on subjective parameters. The current available methods to clinically diagnose VRF include illumination, x-ray, periodontal probing, staining, surgical exploration, bite test, direct visual examination, and operative-microscope examination. All of these have limited success (2–4). Radiographic images could reveal VRF only if the x-ray beam is parallel to the fracture line (5), and thus in many cases radiographic diagnosis is based on other findings like the size and shape of the periradicular lesion and its location (6).

Lately, alternative diagnostic imaging systems with computed tomography were suggested (7, 8). Although these systems could visualize VRF, they all use harmful ionized radiation and present relatively low sensitivity in detection of VRF (7).

Bahcall and Barss (9) suggested a fiberoptic endoscope to image the canal internally, but images of a VRF were never shown by using this system. Furthermore, the minimal thickness of the imaging probe used, 0.7 mm, means that the canal should be enlarged to ISO size 70–80. Such a preparation is seldom performed in adult teeth. Another requirement for the endoscope is a dry canal, which might prove difficult to achieve in teeth with VRF.

Optical coherence tomography (OCT) is a high-resolution imaging technique that allows micrometer scale imaging of biologic tissues over small distances (10). It was introduced in 1991 (11) and uses infrared light waves that reflect off the internal microstructure within the biologic tissues. It achieves a depth resolution of the order of 10 μm and an in-plane resolution similar to the optical microscope. OCT has previously been shown to be a valuable tool in assessing intracanal anatomy, cleanliness of the canal after preparation, and even perforations (12).

The purpose of this experiment was to evaluate the ability of an OCT system to diagnose VRF under different conditions.

Materials and Methods

Twenty-five lower premolars were chosen and accessed coronally with a diamond bur (FG 173; Horico, Berlin, Germany). The canal opening was enlarged with Gates-Glidden drills #3 and #4, which were inserted 4 and 3 mm into the canal, respectively. The canal was instrumented to a size 50 stainless steel K-file (Dentsply Maillefer, Ballaigues, Switzerland). Patency with file size 30 was verified. Irrigation with 2% sodium hypochlorite (NaOCl) by using a 26-gauge needle followed after every instrument, so that a total of 15 mL solution was used per tooth. The teeth were then divided into 3 groups: In the control group (n = 5) and group 2 (n = 10), teeth were flushed with 5 mL of water. In group 1 (n = 10), passive ultrasonic irrigation (PUI) was performed (13), and 10 mL of ethylenediaminetetraacetic acid (EDTA) 17% was used to flush the canals for 1 minute (14). A final flush of tap water followed. After preparation, the external root surface was inspected under a microscope (Zeiss Stemi SV6; Carl Zeiss, Gottingen, Germany) to exclude any external defects or cracks. During these procedures, roots were handled with a wet swab around them to keep them in 100% humidity and to avoid drying. VRF was artificially made immediately after in the 2 experimental groups; a size D stainless steel finger spreader (Hu-friedy, Leimen, Germany) was cut at the tip so its length was 12 mm, and it was inserted as far possible into the canal. Vertical pressure was applied to the spreader with a screw-table until a vertical line appeared on the outside surface of the root. No forces were applied on the control group teeth. A

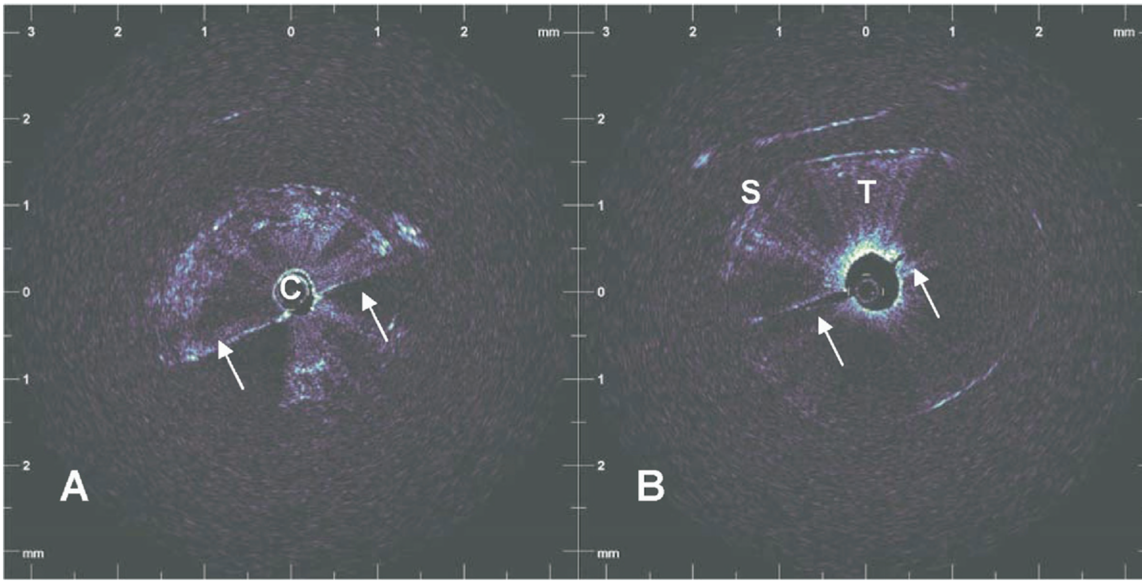

Figure 1. Appearance of VRF through an OCT scan. (*A*) VRF extends through the root 2.5 mm from the apex on 2 opposing sides of the canal; it appears as a bright line. The OCT catheter (C) is inside the canal. (*B*) VRF that has separated the dentin, 8 mm from the apex; the crack can be traced to the external root surface (S), and dentinal tubules can also be identified (T).

stereomicroscope (Zeiss Stemi SV6; Carl Zeiss) with a cold light source (KL 2500 LCD; Carl Zeiss) was used to inspect the roots. Pictures were taken with a camera (Axio cam; Carl Zeiss) at a magnification of ×12 to determine the location of the fracture line along the external surface of the root. All teeth were pooled and scanned with an M2-CV OCT system (LightLab Imaging Inc, Westford, MA) in combination with an ImageWire 2 catheter that has a diameter of 0.3 mm at its thinnest part, with a "pullback" technique (12) starting at the apex. The pullback speed was 1 mm/second, and video files were generated at a rate of 10 frames per second. Each frame consisted of 312 lines, with a scan depth of 3.3 mm in water. Distances were measured from the apex tip.

The presence of VRF in the OCT scan was noted at 3, 6, and 9 mm from the apex by 2 observers. The same observers reviewed the same scans again after an interval of 4 weeks. Interobserver and intraobserver agreement was assessed on the basis of the proportion of agreement and the values of the kappa coefficient. The sensitivity and specificity of the OCT scan in diagnosing VRF were calculated as well as the 95% confidence intervals for both groups.

Results

Several features were observed and illustrated in Figs. 1–3. A bright line extending from the canal (Fig. 1*A*) and 2 bright lines with a void between them separating the dentin (Fig. 1*B*) were both considered a VRF. Fig. 2 compares a microscope photograph with registered OCT imagery, whereas Fig. 3 demonstrates how cracks can propagate inside the dentin.

The specificity and sensitivity are shown in Table 1 and demonstrate high to very high values of the OCT system in diagnosing VRF.

For interobserver agreement, the mean kappa values were 0.9 for group 1 and 0.7 for group 2, showing very good to excellent reliability. For intraobserver agreement, the mean kappa value of 0.9 for both observers shows very high reproducibility. Because the values of sensitivity and specificity of one group fell inside the 95% confidence interval of the other group, we concluded that the groups did not differ in regard to these parameters.

Discussion

According to the current results, more information on the presence of VRF could become available with the use of OCT. No statistical significance for the difference between sensitivity and specificity was demonstrated between the 2 groups. The higher agreement between the observers after the ultrasonic cleaning and use of EDTA could be a result of better light propagation through dentin when the smear layer is absent or cleaner canal devoid of debris. The penetration of light through the dentin tubules allows imaging of structures beyond the canal walls and in some cases up to the cementum layer (12). If the tubules are blocked, less light could penetrate, giving rise to lower-quality imaging beyond the canal walls or in areas where the dentin is thicker.

Two factors might contribute to the development of VRF during the endodontic treatment: First, excessive canal shaping especially in teeth with curved roots or oval canals (15, 16) and excessive removal of tooth structure contribute to the overall weakening of the tooth, which promotes a higher incidence of VRF (17). Second, excessive hand pressure during lateral and vertical compaction of filling material can result in development of VRF (18).The detection of these fractures is usually not made during treatment and is diagnosed only years later (4, 19), leading to bone loss, malfunction of the involved tooth or area, and pain. The immediate identification of a fracture during treatment thus has great clinical value.

There is still confusion in the literature regarding the definition of various terms used to describe different fracture types. Split teeth, vertical fracture, complete, incomplete, primary, secondary fractures, crack, craze line, and other terms are sometimes used interchangeably. Furthermore, a craze line might propagate into a fracture in certain conditions or along different levels of the same root (20, 21) (Fig.3). Although some authors try to define the different terms (4, 22), many others avoid the definitions (16, 20, 23) or only refer to the clinical or diagnostic aspects (24). Still, a VRF is usually referred to as a "through and through" crack with a connection between the canal and the outer root surface or periodontal ligament (21, 25). Because the current study investigated teeth in which a clear fracture line was visible on the

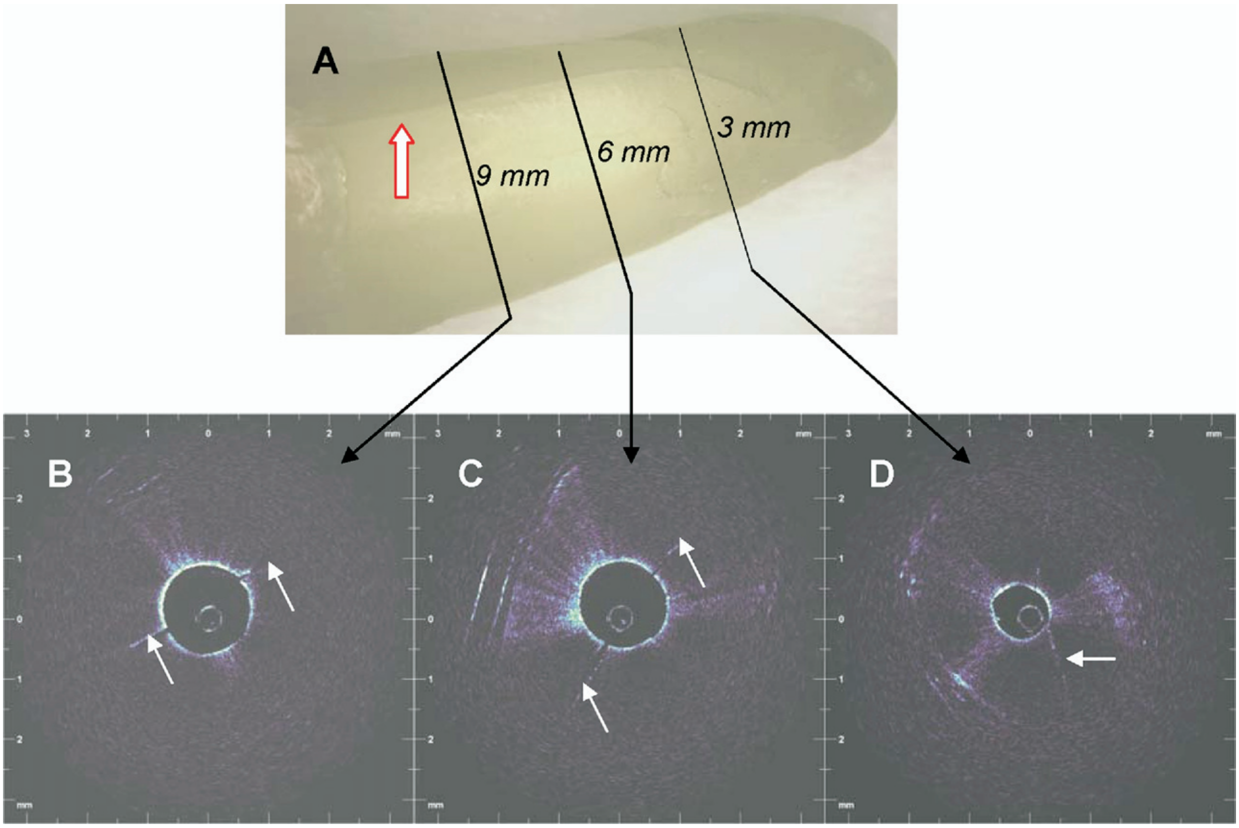

Figure 2. Root sample (*A*) where the fracture is marked by an arrow, and the corresponding OCT images at 9 mm (*B*), 6 mm (*C*), and 3 mm (*D*) from the apex. OCT visualization of the VRF is marked by arrows.

outer surface of the root and the force applied originated from within the canal, a "through and through" defect was assumed. Nevertheless, because OCT is an in situ imaging technique, cracks are always imaged at the site where they originate, and even if they do not propagate all the way to the exterior root wall, they could, in principle, still be imaged with OCT. Although this class of defects was not included in this study, they might be important for future in vitro work.

It is worth noting that there is not yet a commercially available OCT system for dental use. The OCT unit used in this study is designed for intracoronary imaging in atherosclerotic plaque diagnosis and is commercially available for clinical use in cardiac catheterization laboratories. Lantis Laser Inc (Denville, NJ) is currently developing an OCT dental system for lateral scanning, which will allow caries detection and periodontal examination (26). We believe that a specially designed endodontic probe will improve visualization for conventional endodontic treatment and could lead to better decision making and elevated standard of care.

In conclusion, OCT represents a powerful tool for evaluating VRF and has the potential to both identify VRF and detect its specific location

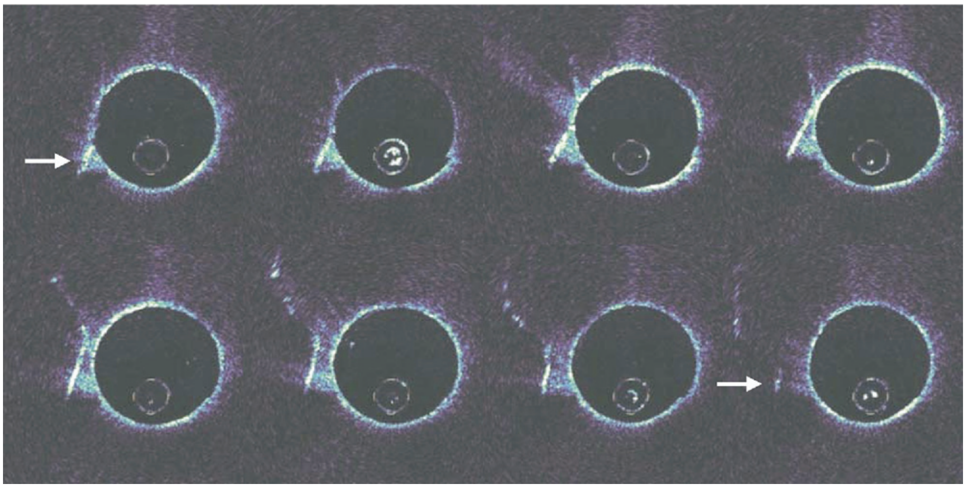

Figure 3. Sequence of video frames from a pullback, recorded approximately 4.5 mm from the apex, spaced 0.1 mm apart. A crack (white arrow) that originates in the canal (top left frame) can be followed as it propagates in the dentin.

TABLE 1. Sensitivity and Specificity of Detecting VRF with OCT (%)

	Group 1	Group 2
Observer A		
Sensitivity	95	95
Specificity	100	100
Observer B		
Sensitivity	91	74
Specificity	89	91
Overall		
Sensitivity	93	85
Specificity	95	96

VRF, vertical root fracture; OCT, optical coherence tomography.

along the root. In vivo studies are needed to substantiate the clinical usage of OCT during endodontic treatment.

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