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CASE REPORT

Diagnosis of vertical root fractures in endodontically treated teeth utilising Digital Subtraction Radiography: A case series report

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Abstract

Vertical root fractures are commonly associated with root-filled teeth. Diagnosis is challenging because the clinical signs are not completely pathognomonic, and conventional periapical radiography is often unreliable. Digital subtraction radiography (DSR) is able to detect small radiographic changes between two successive radiographs by subtracting out consistent radiographic elements. Its use could possibly assist in the diagnostic procedure. Four cases are presented to demonstrate the potential use of DSR in the detection of vertical root fractures in endodontically treated teeth. After the digital subtractions had been carried out, a dark line in the body of the roots was distinguishable, raising the possibility of the presence of a vertical root fracture. The use of contrast enhancement and pseudocolouring techniques assisted with the diagnosis of vertical root fractures. DSR proved to be a useful diagnostic tool for the detection of vertical root fractures in these four clinical cases.

Introduction

Vertical root fracture (VRF) is defined as one of five fracture types (1). VRFs are longitudinally oriented fractures that frequently pose a diagnostic challenge to clinicians (2). They are described as complete or incomplete fractures located in the root portion of the tooth and propagate coronally, often in a bucco-lingual direction. Postplacement and obturation forces during root canal filling are considered the main causes of VRFs in endodontically treated teeth. Occlusal forces, wedging of restorations, corrosion, expansion of metallic posts and postsurgical retrograde restorations have long been considered, but have yet to be convincingly demonstrated, as causes of VRFs (3).

The clinical symptoms and radiographic indicators of VRFs are not entirely pathognomonic and therefore the patient's dental history is often non-contributory (4). Unexceptional clinical findings are tenderness to percussion and biting, swelling and an associated sinus tract, an isolated deep periodontal pocket and localised pain (5). Radiographically, in many of the cases, bone resorption is characteristic, including angular resorption at the cervical area. A 'J-shaped' radiolucent area is frequently evident, extending from the apex along a lateral root surface (6). Confirmation of a VRF is made either after extraction of a tooth, following flap reflection, or complete radiographic separation of the fragments. Fuss *et al.* (7) reported that VRFs are found in approximately 10% of extracted teeth having had endodontic treatment.

A variety of radiographic imaging systems are available in dentistry for the detection of VRFs. Some of them are widely applied in clinical practice: Digital Periapical Radiography (DPR), Cone Beam Computed Tomography (CBCT) (8, 9), while others have only been used in experimental studies; Micro-Computed Tomography (μ-CT) (10), Tuned Aperture Computed Tomography (TACT) (11), Optical Coherence Tomography (OCT) (12), Local Computed Tomography (LCT) (13), Flat-Panel Detector-based Volume CT (FD-VCT) (14). Youssefzadeh *et al.* (15) used the Multidetector Computed Tomography (MDCT) in a human study to detect VRFs.

In the four clinical cases presented here, a digital subtraction image processing software –EIKONA Subtraction

Radiography (developed by Artificial Intelligence and Information Analysis Laboratory, Department of Informatics, Aristotle University of Thessaloniki, Greece) was used to evaluate the suitability of a Digital Subtraction Radiography (DSR) technique for the diagnosis of VRFs in endodontically treated teeth.

DSR is a radiographic image analysis technique able to detect small radiographic changes between two successive radiographs by removing the unchanging anatomic distractions. The function of the software is based on the registration of the two input digital radiographs and further refinement of the processing. Several pairs of user-defined landmark points are selected on both radiographs to correct the geometrical distortions (rotation, scaling, translation), prior to their subtraction. The pairs of the selected landmark points must correspond to the exact anatomical structures on the two radiographs. A magnification window assists the user to precisely select the landmark points. The registration procedure includes both the selection of the landmark points as well as a refinement step that improves the initial registration results using image intensity information. Registration is succeeded by a normalisation process which eradicates brightness and contrast differences between the two images. The last step of the procedure involves the superimposition and the subtraction of the two radiographic images. Areas where the two radiographic images have the same visual intensity are presented as grey. These areas where the recent radiograph is more radio-opaque than the first present as white, while regions where the recent radiograph is more radiolucent are dark. The use of contrast enhancement techniques (CEt) on the DSR images provides greater distinguishing ability over a uniform grey background. The use of pseudocolouring techniques (PCt) indicates the radiographic areas which are of greatest importance in the diagnostic process (16).

The purpose of this case series report is to present and discuss the potential of DSR as a diagnostic tool for the early detection of VRFs.

Cases presentation

The medical histories of all the patients were non-contributory. Following access, the root canals were instrumented using the ProTaper Next Ni-Ti rotary system (Dentsply-Maillefer, Maillefer Instruments SA, Ballaigues, Switzerland) and irrigated with 2.5% NaOCl. EDTA paste (Glyde, Dentsply-Maillefer) was used as a lubricant and calcium hydroxide the inter-appointment medicament. The canals were obturated with lateral condensation of gutta-percha and Roth's 801 sealer (Roth International Ltd., Chicago, IL, USA). The patients were then recalled after 6, 12, 18 and 24 months. Radiographs for each case were taken under identical conditions using the RadioVisioGraphy (RVG) direct digital intraoral radiography system (Trophy Radiology S.A., Paris, France) and an Oralix AC Densomat X-ray machine (Gendex Dental System, Milano, Italy, 65 kV peak and 7.5 mA mean). All radiographs were taken using the parallel technique using intraoral sensor alignment instruments [Hawe Super-Bite (Hawe-Neos Dental, Bioggio, Switzerland)]. In all cases, DSR imaging was carried out using the post-operative and the most recent radiograph, usually taken when the patient presented with pain. With the assistance of DSR imaging, the boundaries and the exact dimensions of the periapical radiolucencies became clearly distinguishable; dark lines in the body of the roots were also visible corresponding to the possible fracture lines. The resultant digital subtractive image (DSI) was further processed using the CEt and PCt provided by the software; the potential fracture lines were coloured red. The presence of a VRF was determined in all four cases but was only confirmed after optical observation following the extraction of the tooth or flap elevation.

Case 1

A 60-year-old female patient was referred to our clinic for endodontic treatment for tooth 34. Three years post-treatment, the patient presented with symptoms, namely 'when I bite dry hard food, it's painful'. Clinical examination revealed tenderness to percussion and biting while periodontal examination revealed a narrow 9 mm probing depth at the mesial area of the root. The DSR appliance raised the possibility of a VRF, and the tooth was scheduled for extraction due to its poor prognosis (Fig. 1).

Case 2

A 60-year-old female patient was referred for endodontic treatment for tooth 14. Three years later, the patient presented with symptoms describing '... a "bubble" in my gums. The taste in my mouth is often bad'. Clinical findings were swelling and sinus tract. Periodontal examination revealed a narrow and deep periodontal pocket at the mesio-buccal area. Following flap reflection and optical observation of the VRF, the buccal root was amputated (Fig. 2).

Case 3

A 55-year-old female patient was referred for treatment of tooth 45. The root had a crown fracture, and a diagnosis of irreversible pulpitis was made. Endodontic

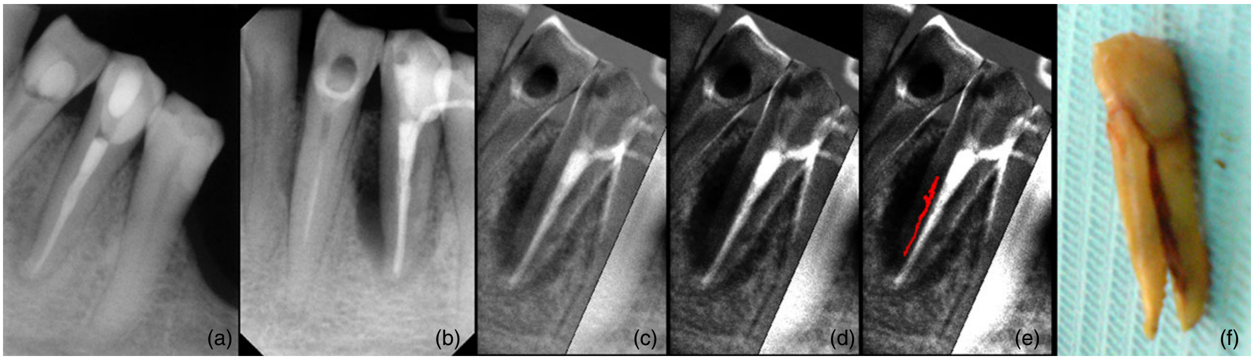

Figure 1 (a) Post-operative radiograph. (b) 3 years later: radiolucency in the proximal area and the apical third of the distal area. No fracture line can be observed. (c) Result of digital subtraction of b from a: a dark line in the body of the root at its mesial part is visible. (d) DSI processed using CEt. (e) Image d processed using PCt (f) VRF in the extracted tooth.

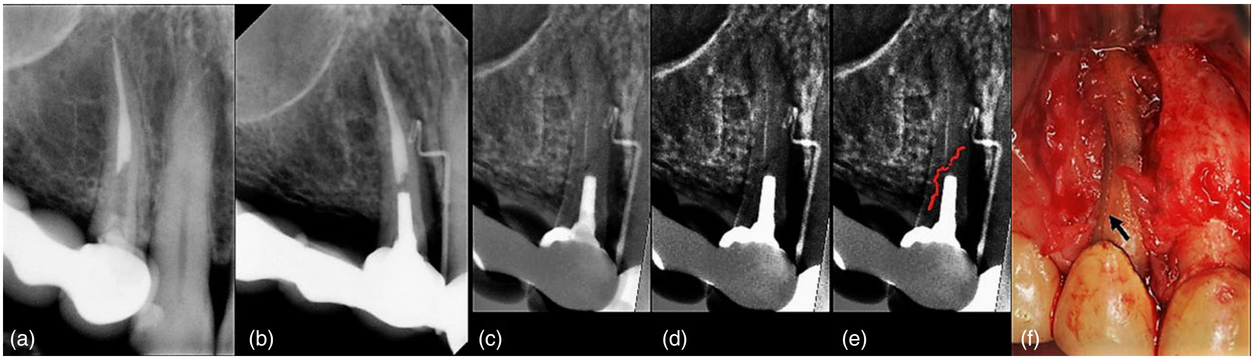

Figure 2 (a) Post-operative radiograph. (b) After 5 years: 'J-shaped' radiolucency in the mesial area and the apical third of the root. No fracture line is visible. (c) Result of digital subtraction of b from a: an oblique dark line in the body of the root is evident at its mesial part. (d) DSI processed using CEt. (e) Image d processed using PCt. (f) VRF revealed after flap reflection.

treatment was carried out, the patient was scheduled for recall and referred back to her general dentist for a new crown. After 12 years, the patient returned and detachment of the crown of tooth 45 was noted. Her chief complaint was 'my crown fell off'. DSR revealed a dark horizontal line at the apical part of the body of the root; no clear signs of the exact propagation of the fracture line were evident although. Confirmation of VRF was made following tooth extraction, with the dark horizontal line visualised in the DSI corresponding to the apical part of the VRF. The vertical propagation of the fracture at the adjacent surfaces of the root was not distinguished from the DSR (Fig. 3).

Case 4

A 45-year-old male patient was referred for endodontic treatment for tooth 37. The patient had previously suffered a supragingival crown fracture on the lingual surface of tooth 37. Root canal treatment was performed and the patient was subsequently referred back to his clinician for a crown. The patient was seen six years after the prosthodontic treatment, his chief complaint being bite sensitivity. Periodontal examination revealed a narrow and deep periodontal pocket at the buccal area towards the furcation of the roots. The crown was removed and subgingival curettage performed. Despite this treatment approach, no healing process was observed and the presence of VRFs was determined. The tooth was extracted (Fig. 4).

Discussion

Diagnosis of a VRF imposes one of the biggest challenges in endodontics (3). The diagnostic accuracy of the most common clinical and conventional radiographic signs has been questioned on the grounds of lack of evidence-based data (17). The detection of VRF as early as possible is important to pre-empt any non-beneficial treatment and to reduce bone loss.

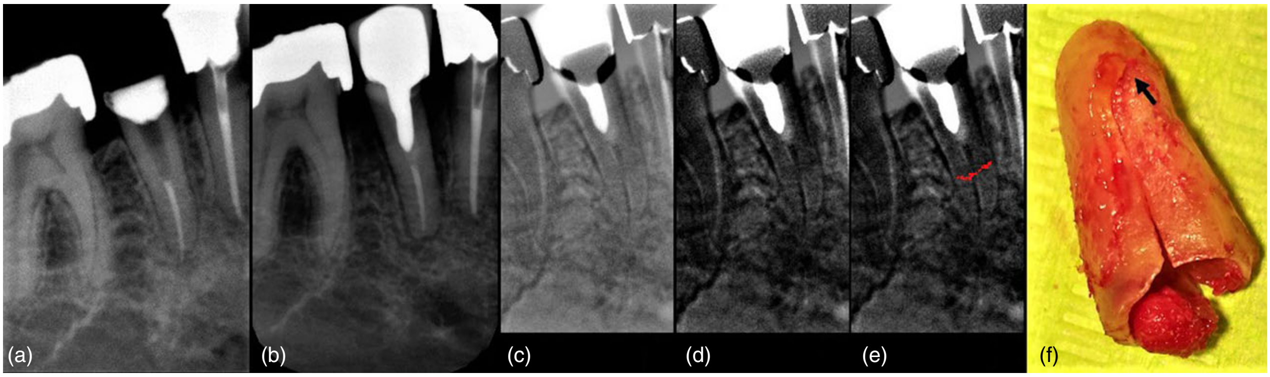

Figure 3 (a) Post-operative radiograph. (b) After 12 years: 'J-shaped' radiolucency in the mesial area as well as a radiolucent area at the apical third of the root. No evidence of a VRF (c) Result of digital subtraction of b from a: a dark horizontal line in the body of the root can be distinguished at its apical part. (d) DSI processed using CEt. (e) Image d processed using PCt. (f) VRF was confirmed after the extraction of the tooth. The arrow indicates the horizontal part of the VRF corresponding to the line visualised with the DSR and pseudocoloring.

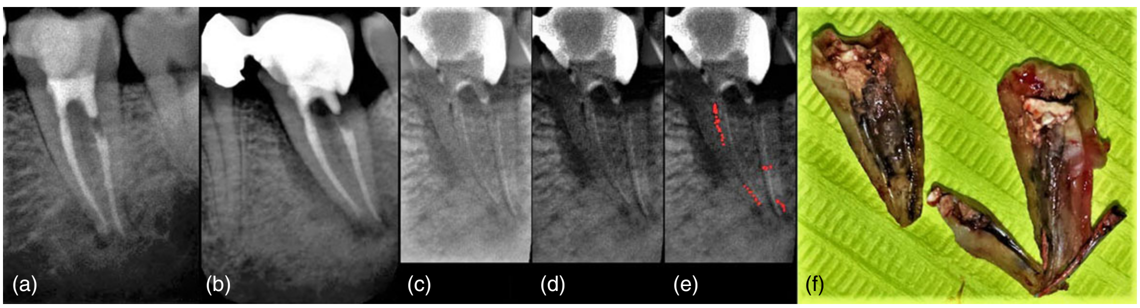

Figure 4 (a) Post-operative radiograph. (b) After 6 years: radiolucency towards the furcation area of the roots, the mesial and apical area. No fracture line is visible. (c) Result of digital subtraction of b from a: a dark oblique line in the body of the root at its mesial part is visible and two smaller in the distal root. (d) DSI processed using CEt. (e) Image d processed using PCt. (f) VRF was confirmed after the extraction of the tooth.

In the cases presented, following the subtraction to enhance the images, not only did the boundaries of the lesions become more distinguishable but also a dark line indicating the fracture line was visible. The fracture line was precisely located after the further processing of the image (pseudocolouring and contrast enhancement).

DSR was first introduced to dentistry as an experimental tool in periodontics enabling an enhanced potential for radiographic diagnosis even in cases of small changes in bone structure. This technique appears to be useful in the detection of changes in both cortical and cancellous bone, significantly improving the accuracy of diagnosis (18). In addition, follow-up studies confirm the significance of DSR as a method for evaluating the healing process of periapical lesions (19). Grondahl *et al.* demonstrated the significance of DSR as a tool for the early and effective diagnosis of dental caries (20) while a number of researchers have also described the advantages of DSR in the field of oral implantology, notably osseointegration and the healing of peri-implant lesions (21). DSR has also been used in orthodontics and in the diagnosis of defects of the temporomandibular joint (22, 23). Andersen and Wenzel have used DSR in forensic dentistry as an aide in simulated victim identification (24).

In endodontics, DSR has been used in assessing healing and in detection of small changes in periapical lesions. *In vitro* studies have shown DSR to be of use in the diagnosis of internal and external tooth resorption (25, 26). While in another *in vitro* study, different instrumentation techniques were evaluated with the use of DSR (27).

In a recent *ex vivo* study, Queiroz *et al.* (28) found the accuracy of DSR in the detection of VRFs to be acceptable. To the best of our knowledge, this is the first attempt to use DSR in clinical conditions, as a diagnostic tool of VRFs in endodontically treated teeth. The results from this case series indicate that further clinical studies should be carried out, measuring the accuracy, sensitivity and specificity of DSR in detecting VRFs in root-filled teeth. The diagnostic sensitivity of the DSR technique should also be compared to others, such as conventional periapical radiographs, CBCT, μ-CT and MDCT.

Several studies have presented cases of endodontically treated teeth with VRFs, where CBCT was used to reach to the final diagnosis (5, 29). However, *ex vivo* studies that have evaluated the diagnostic accuracy of CBCT in root-filled teeth did not find significant differences when compared with digital periapical radiographs (8, 9). Moreover, indications for carrying out CBCT are restricted in cases that periapical radiographs cannot provide adequate information for diagnosis (30).

It is apparent that the radiation dose in DSR complies better with the 'As Low As Reasonably Achievable' (ALARA) principle than other more recent imaging techniques. The cost of the technique is also significantly lower, as no further equipment (apart from software) is required. The subtraction process is easy to apply and not time-consuming as it can be carried out immediately following the most recent radiograph, and its use does not require special skills. The contrast enhancement and pseudocolouring techniques improve the distinguishability of the VRFs.

However, DSR does have its limitations –radiographs to be digitally subtracted must share the same characteristics, including brightness, colour contrast and acquisition geometry. This may impose procedural difficulties in clinical practice (16, 18). On the other hand, the progress in computer technology has achieved reduction in the structural or anatomical 'noise' as well as the correlation of variations in exposure and projection geometry using built-in algorithms. This allows the digital subtraction to be carried out even when the radiographs do not strictly comply with the original requirements. Another limitation is the difficulties in reproducing radiographs under constant conditions. For this reason, any adjustment helping to guarantee standardisation is preferable (cephalometric head stabilisation and impression materials adjusted at the alignment instruments) (31). Finally, the limitations of periapical radiography also affect DSR. The presentation of a three-dimensional object in two dimensions and superimposition can lead to misdiagnosis. It has also been stated that the X-ray beam should pass through the fracture line for certain diagnosis (32).

DSR is a technique which could be considered as an assistive diagnostic method in endodontic clinical dilemmas such as the detection of VRFs. Conventional diagnostic methods continue to be of importance in the diagnosis of VRFs and modern techniques cannot always be substituted; however, through the four cases presented here, carrying out DSR before applying other imaging methods of greater cost and radiation dose proved significant. Further research studies should be conducted evaluating the potential use of DSR in the detection of VRFs.

Authorship declaration

All authors have contributed significantly and are in agreement with the manuscript.

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