ABSTRACT

Background: Vertical root fractures (VRF) can be defined as either complete or incomplete fractures that occur predominantly in endodontically treated teeth (ETT). The clinical symptoms and conventional radiographic techniques are not always accurate, which can lead to diagnostic errors. This motivated us to seek new, better techniques that can improve the prognosis and treatment of ETT with vertical fractures.

Objective: The aim of this study was to investigate the potential of three novel techniques: Cone Beam Computed Tomography (CBCT), Optical Computed Tomography (OCT) and 3D Profilometry for the visualization and assessment of VRF.

Methods: The study involved intact human premolars, extracted for orthodontic or periodontal reasons. The teeth were then endodontically treated and restored with prefabricated metal posts. No additional preparation of the coronal hard dental tissues was performed, apart from the access cavity. After thermocycling, their fracture resistance was evaluated in a standard testing machine. The resulted vertical fractures and crack propagation were evaluated using CBCT, OCT and 3D Profilometry.

Results: The CBCT provided visualization of the tooth in three planes: axial, coronal and sagittal. Root fractures were observed at the coronal and middle 1/3 of the root. The OCT provided highly-detailed, biomicroscopic cross-sectional images of the mesial and distal root surfaces. The images, obtained with 3D Profilometry showed the surface topography and provided precise information about the width and depth of the VRF.

Conclusion: All of the techniques used in this study proved to be highly informative, non-invasive and non-contact methods, suitable for the evaluation of VRF.

Key words: OCT, CBCT, Profilometry, fractures, premolars, endodontically treated teeth.
After that, they were embedded in a self-curing resin to a level 2 mm apical to the cementoenamel junction (CEJ). The technique was modified, based on the one used by Soares et al. [3]. The periodontal ligament was simulated by a polyether-based impression material (Impregum Garant L Duo Soft, 3M ESPE). The procedure consisted of the following steps: isolation of the roots in melted wax to a point 2 mm apical to the CEJ, stabilization of the teeth by a radiographic film with a circular hole, positioning of the tooth in a plastic cylinder (25 mm in diameter and 35 mm in height) and insertion of the self-curing resin. After the polymerization of the resin, the teeth were removed and the wax was cleaned from the roots. The polyether was placed in the resin and the teeth were re-inserted until the setting of the material. The specimens were then subjected to the static fracture resistance test by using a universal testing machine (Fu1000e, Germany). They were loaded in compression at a constant speed of 4 mm/min along the tooth axis until failure. The teeth were inspected under magnification and their fracture modes were determined. A premolar, representative of the most common mode of failure, was evaluated using three visualization techniques:

1. Cone-beam computed tomography (CBCT). The apparatus used was Galileos Comfort (Dentsply Sirona). The scans provided imaging in the axial, coronal and sagittal planes.

2. Optical coherence tomography (OCT). The apparatus used was RTVue Premier (OptoVue, USA) with a resolution of 5 µm and wavelength λ=840±10 nm. Every scanning cycle provided 17 raster scans of the investigated area (6x4 mm in size).

3. 3D Profilometry. The instrument used was Zeta-20 (Zeta Instruments) with a vertical (Z) resolution less than 1 nm, field of view between 0.006 mm² to 15 mm² and magnification of 5x, 20x, 50x and 100x.

RESULTS

The CBCT provided visualization of the tooth in three planes: axial, coronal and sagittal (fig.1). On the axial scan, there is a visible fracture line, starting from the root canal and extending towards the outer surface of the tooth. On the coronal scan, there is a horizontal fracture in the area of the cemento-enamel junction, as well as an oblique fracture, located in the middle 1/3 of the root. The latter can also be observed on the sagittal scan, originating from the tip of the cemented metal post.

**Fig. 1.** CBCT of a representative specimen, restored with a prefabricated metal post. A. axial view; B. Coronal view. C. Sagittal view. The visible fractures are indicated with an arrow.
The OCT provided images of the mesial and the distal sides of the tooth (fig. 2 and 3). Both the coronal tissues and the composite restoration are fractured, exposing the metal post. On the distal side of the root, there is a vertical fracture that extends apically. Its propagation towards the depth of the dentin can be seen at the sliced images.

**Fig. 2.** OCT image of the mesial side of the tooth.
Fig. 3. OCT images of the distal side of the tooth.

The 3D profilometry provided information about the topography of the examined surface, as well as the width and the depth of the observed fractures (fig. 4 and 5). The width of the examined cracks is between 3.2 µm and 6.5 µm, and their depths – between -4 µm and 7.8 µm.
DISCUSSION

The diagnostic capabilities of the cone-beam computed tomography exceed those of the traditional radiographic techniques – the images provide information about the examined objects in three planes [4, 5]. This makes the method especially useful in diagnosing root fractures. Our results showed both horizontal and oblique fracture lines, as well as their propagation and localization in relation to the surrounding tissues and materials (dentin, enamel, cement and metal post). One of the possible disadvantages of the method is the negative effect of the metal posts, as well as the gutta-percha filling material. The studies show that their presence can decrease the accuracy of the images [6, 7]. This is especially evident on the sagittal scans of our study (fig. 1, C). Nevertheless, this can be compensated by the settings of the CBCT apparatus – the ability to detect root fractures is not significantly decreased [7]. Overall, according to Talwar et al., CBCT scans show better sensitivity and specificity than periapical radiographs in the detection of root fractures [8].

The OCT provides highly detailed images with great resolution, comparable to this of histological studies. Moreover, it can give additional information that cannot be obtained with CBCT. For example, there is a vertical root fracture present on the distal side of the examined premolar (fig. 3), which cannot be seen on the CBCT images. Another advantage of this method is the absence of any ionizing radiation, which is not the case with CBCT. A disadvantage of the method is its inability to perform scans of the root canal in clinical conditions, because of the presence of the bone and the gingiva. Shemesh et al. develop a method for intracanal detection of root fractures, using an OCT catheter, used in cardiology [9]. The results are promising, with an overall sensitivity of 93% and specificity of 96%, which
makes this technique a promising non-destructive method for the diagnosis of vertical fractures.

The results from the 3D profilometry provided both quantitative and qualitative information about the observed fractures. There is no information in the literature about the application of the method in endodontics. Till now, the capabilities of the profilometry were used in the investigation of deep carious lesions, demineralized areas, stains and cracks [10]. There is no need for any sample preparation procedures, the technique is fast and the details provided are of nanometric scale. The only possible disadvantage is the limited filed of view and the need of a direct contact with the examined surface.

**CONCLUSIONS**

All of the techniques used in this study proved to be highly informative, non-invasive and non-contact methods, suitable for the evaluation of root fractures.

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