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The Impact of Fractured Endodontic File Removal on Vertical Root Fracture Resistance: Three-Dimensional Finite Element Analysis

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Abstract - *This study investigated by means of finite element analysis the influence of fractured file removal on root fracture resistance in an endodontically-treated canine. A 4mm fragment of an endodontic file was deliberately fractured in the apical third of an upper canine root and removed by ultrasonic tips. Micro-computed tomography scans were carried out before and after fractured file removal on the same tooth. Two 3D-FE models (before and after file removal) were subjected to 100N loading. Results indicate that the fractured file removal increased von Mises stresses by 55%. Peak stresses were located around the root filling/dentine interface prior to file removal. Following file removal, peak stresses were concentrated at the buccal root surface/bone interface that might initiate vertical root fracture buccolingually.*

KEYWORDS**:** Vertical root fracture, stress analysis, finite element analysis.

INTRODUCTION

Despite the advancement in manufacturing of nickel-titanium (NiTi) endodontic file systems, which have higher cyclic fatigue resistance compared with conventional stainless steel files, fracture of endodontic files during endodontic instrumentation is not an uncommon complication[1]. There are several factors which might contribute to the fracture resistance of endodontic files; instrument design, material properties, surface treatment, heat treatment, machining and root canal curvature. It was reported that the stiffer the instrument and more curved the root canal the lower the fracture resistance of the NiTi rotary instrument[1-2].

Tortional (ductile) fracture and cyclic fatigue (brittle) fracture or both are the principal mechanisms for NiTi instrument separation in narrow curved root canals, notwithstanding their low modulus of elasticity and high resistance to tortional stresses. It has been recently indicated that Vortex NiTi rotaries (Dentsply Tulsa Dental, Tulsa, OK) at higher speed rotation may reduce applied torque and increase fracture resistance[3]. Instrument fracture analyses have indicated that most of fractured NiTi files were located in the upper molar teeth predominantly (>50%) in curved mesiobuccal canals at the apical third [4-5]. Similarly, it was reported that file separations are predominantly seen in curved canals with an 87% success rate in removing these separated files when a microscope was used[6].

However this success rate varies depending on the clinicians experience and the location of the fractured instrument, which might drop to 37.5% when the instrument is fractured apically [7].

In a UK dental survey it was shown that more file separation was experienced by specialist endodontists than general dental practitioners (GDPs), however, both agreed that removing fractured instruments should be carried out by ultrasonic tips or bypassed if possible and no attempt should be made if the instrument removal will compromise the structure and restorability of the involved tooth. Most GDPs opted to leave the fractured instrument when it is located apically [8-9-10].

The removal of separated instruments, which is a technique-sensitive procedure and needs specialist clinical skills, has been perceived as a necessary procedure for adequate three-dimensional sealing of the root canal system and the overall success of the restorative treatment. However, the retrieval of fractured instruments might compromise the quality and quantity of remaining tooth tissues and consequently tooth fracture resistance. The risk of root fracture depends on the location of the separated instrument, and the method being used to remove it: tooth fracture resistance is significantly decreased when the removal is attempted at the apical third [2]. Conversely, leaving the fractured element in place resulted in insignificant difference in tooth fracture resistance compared with sound tooth [11-12].

AIM

The purpose of this study was to investigate, by means of three-dimensional finite element analysis (3D-FEA), the influence of fractured file removal from the apical third on the root fracture resistance of an endodontically-treated canine root. The null hypothesis to be tested is that no difference in stress distribution patterns and peak stress values will be observed before and after fractured file removal under vertical loading.

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MATERIALS AND METHOD

An extracted human canine tooth was decoronated and scanned by micro-computed tomography (μ-CT) (SKyscan, Kontich, Belgium). Following the first scan, a 4mm fragment of F5 Protaper endodontic file (Dentsply Maillefer, Ballaigues, Switzerland) was deliberately fractured within the apical third of the canine root. The file was notched to a half of its thickness with a diamond bur 4 mm from the instrument tip and rotated at 400 rpm and torque of 3Ncm in the root canal apical third with pressure applied whilst rotating. The fractured file tip was 1 mm short of the apex. Under microscopic visualisation, modified Gates Glidden burs (no 2–4) (Dentsply Maillefer, Ballaigues, Switzerland) were used at the coronal aspect of the fractured file to create a platform and locate the fractured file. CPR ultrasonic tips number 5, 6 (Obtura-Spartan, Fenton, MO, USA) were used at a low power-setting to trephine dentine around the fragment. Subsequently, the fractured file became loose and removed as a single piece. Patency was confirmed with a K-file (size 10) to ensure that no metal fragment was left in situ. The time required for the removal of the fractured file was about 25min[12].

The root canal was subsequently obturated with gutta-percha (GP). Repeated post-operative μ-CT scanning, under identical settings, was carried out on the same canine root following the removal of the fractured file. Subsequently, scans were imported as a stack of images by ScanIP (Simpleware, Exeter, UK) for three-dimensional (3D) reconstruction. A block of alveolar bone (15x15x25mm) was created around the root using ScanCAD (Simpleware, Exeter, UK).

Depending on pixel density, three masks were generated on each slice; these masks represent dentine, GP root filling and supporting bone around the root. A periodontal ligament was not modelled as it is relatively thin and because of the difficulty in getting a uniform thickness all around the root dentine. Two 3D models were developed out of the segmented masks to represent a filled canine root before and after fractured file removal (Fig1-A).

A finite element mesh was generated on both 3D models (Fig1-B) using scanIP. Mesh generation was dependent on pixel density, however, convergence study confirmed 95% accuracy in both models. Details of these FE meshes are included in Table I. Both 3D-FE models were imported by Patran (MSCsoftware, CA, USA) for pre and post-processing, Material properties were considered isotropic, linearly elastic and homogeneous (Table. II). Boundary conditions and loading were identified in Patran, supporting bone was constrained in all directions (x=0, Y=0, Z=0, XY=0, XZ=0, YZ=0) apart from the occlusal surface. 100N loading was applied vertically on the root dentine and GP surfaces along the long axis of the root (Fig1.C). All FE linear solutions were carried out using Nastran (MSCsoftware, CA, USA); results were post-processed and plotted by Patran software.

Table 1. *Details of the finite element meshes of both models.*

Model-1 (pre-removal)		*Model-2 (post-removal)*	
Nodes	Elements	Nodes	Elements
302730	854399	331226	965089

Table 2. *Mechanical properties of all materials included in the FE models* [13,14,15,16,17].

Materials	*Young's Modulus (MPa)*	*Poisson's Ratio*
Bone ([13])	14000	0.16
Dentine ([14,15,16])	18600	0.31
Gutta-Percha ([17])	690	0.45

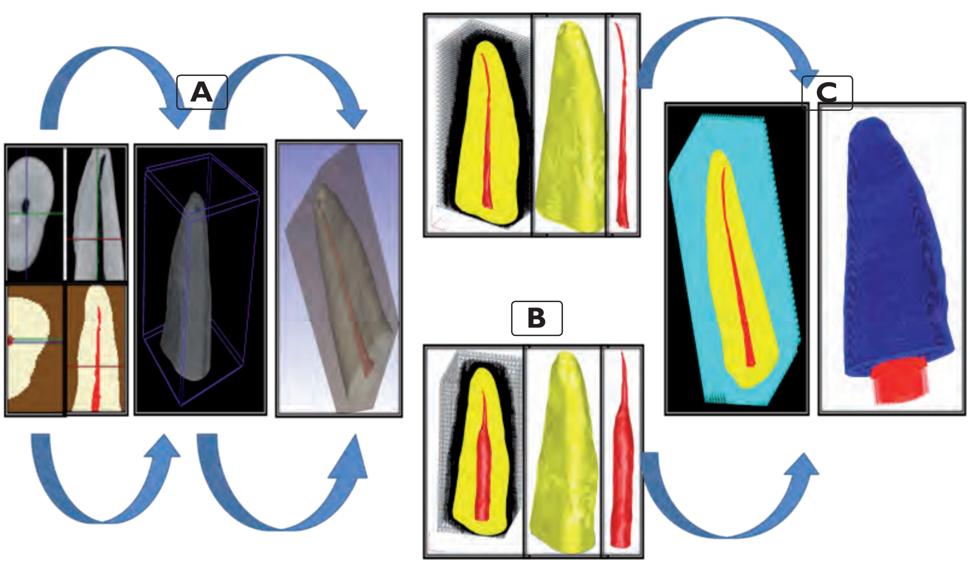

Figure 1. *A: Image-based modelling of the canine root by generating masks on different sections (A) using Scan IP; B: FE meshes generated on both models before file removal (Top) and after file removal (bottom) using scan FE ; C: Materials properties, boundary conditions, and loading conditions were applied in Patran*

RESULTS

The results of this study indicated that the level of von Mises stresses within the root before removing the separated instrument was lower (119MPa) than the stresses generated after removing the separated instrument which were increased by 55% (191MPa) under similar loading conditions by applying 100N vertically. The location of the maximum stresses was in the middle of the root surface (coronal direction) at the junction of the root GP filling material with the root dentine in the pre-removal stage (Fig.2). Conversely, peak tensile stresses were concentrated mid-buccally towards the root/bone interface of the root in post-removal stress analysis (Fig.3).

Similarly, maximum principal stresses were 40MPa and 59MPa within the root dentine before and after file removal, respectively. While the peak maximum principal stresses concentrated within the root canal, the removal of the fractured instrument, which resulted in removing a substantial amount of root dentine, shifted the location of the peak maximum principal stress to the mid buccal surface of the root dentine (Figs. 4, 5).

The maximum principal stresses within the root filling material increased from 50 MPa to 56MPa by increasing the root canal volume following the removal of the fractured file (Figs. 4, 5). Similarly, the supporting bone suffered a higher level of compressive stresses after removing the

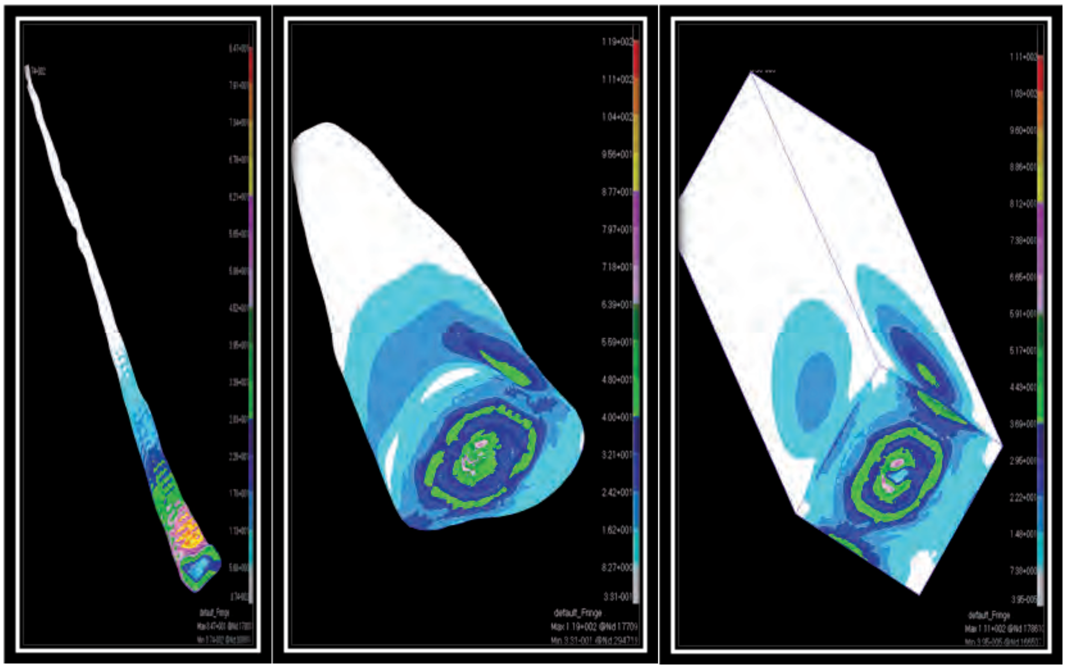

Figure 2. *von Mises stresses within root filling, root dentine and the whole structure under vertical loading before the removal of fracture file.*

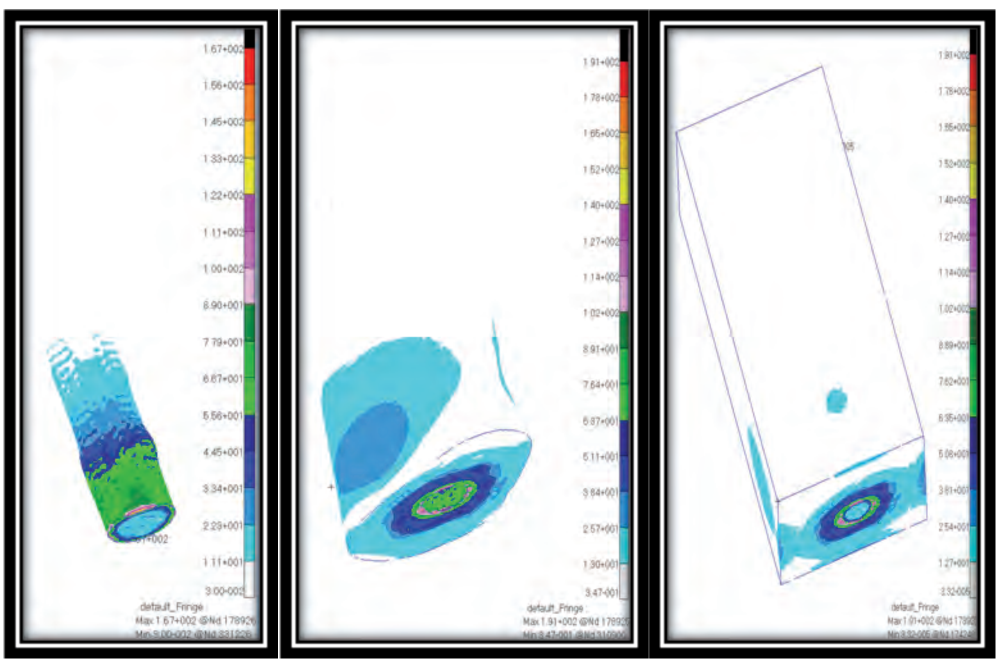

Figure 3. *von Mises stresses within root filling, root dentine and the whole structure under vertical loading following the removal of the fractured file.*

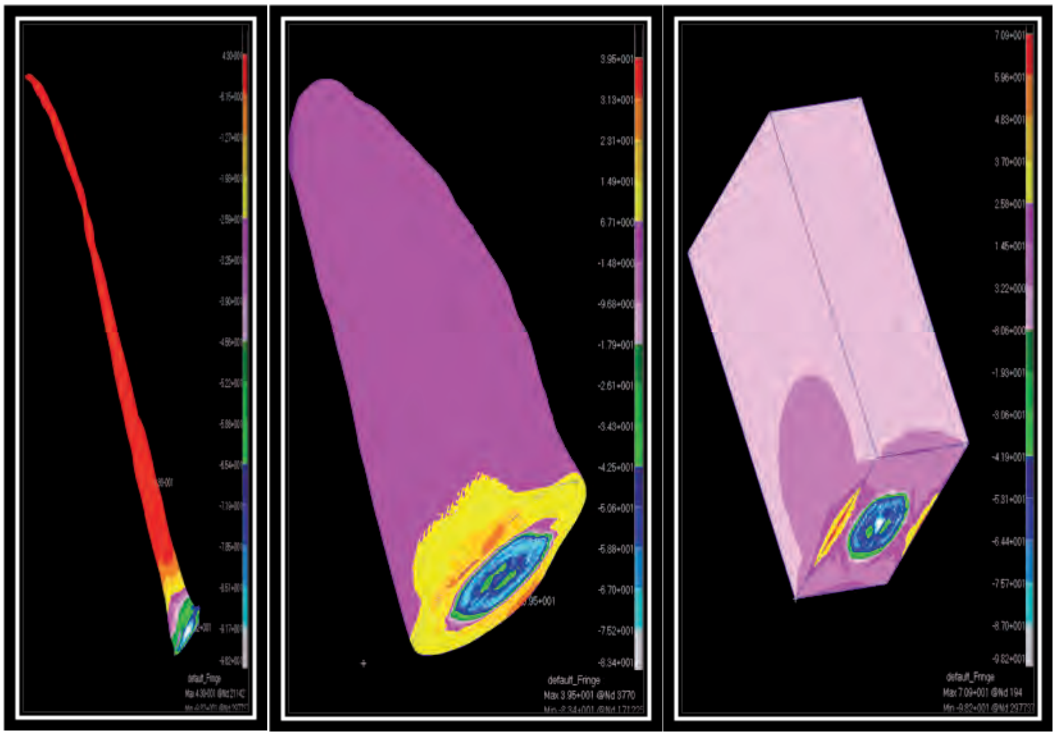

Figure 4. *Maximum principal stresses within the root filling, root dentine and the whole structure under vertical loading before the removal of fractured file.*

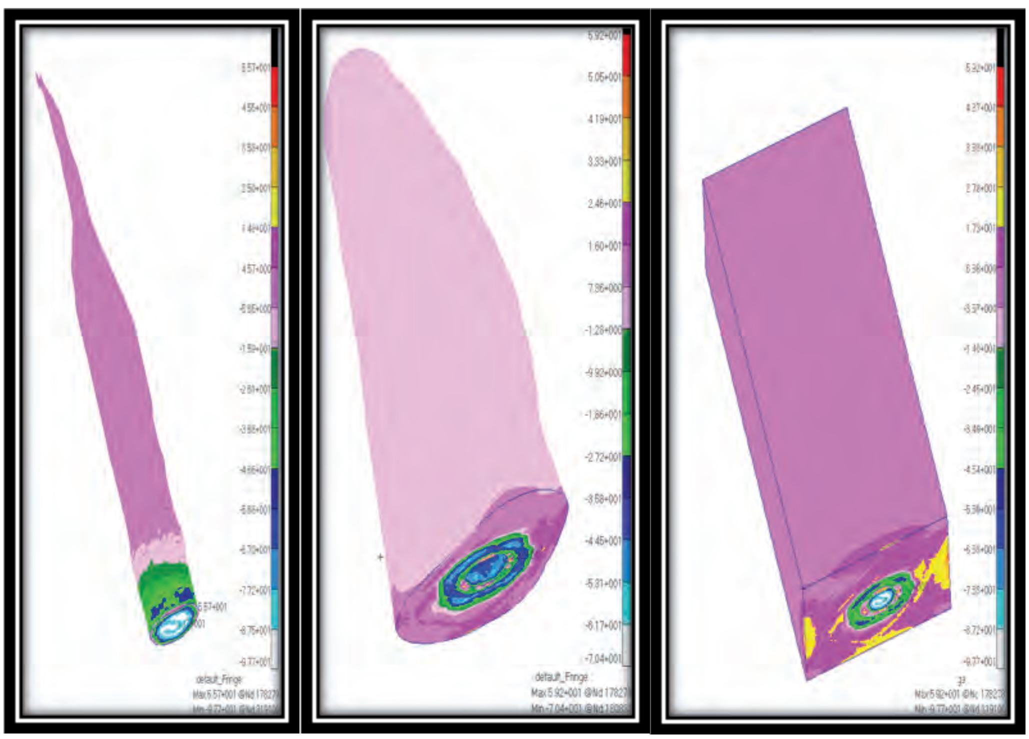

Figure 5. *Maximum principal stresses within the root filling, root dentine and the whole structure under vertical loading after the removal of the fractured file.*

fractured file especially at the surface engulfing the buccal surface of the root dentine (Figs 2, 3).

The amount of root displacement, however, was almost similar in both scenarios. The vertical loading on the GP and dentine has resulted in 0.9μ apical translation (Fig.6). This deflection was slightly increased (1μ) after the removal of the fractured file (Fig.7).

DISCUSSION

This study has looked into the effects of removing a fractured instrument during root canal treatment on the root fracture resistance and the pattern of stress distribution within the root canal, root dentine and supporting bone. The use of FEA based on models generated by micro CT scans, segmented by pixel density and reconstructed

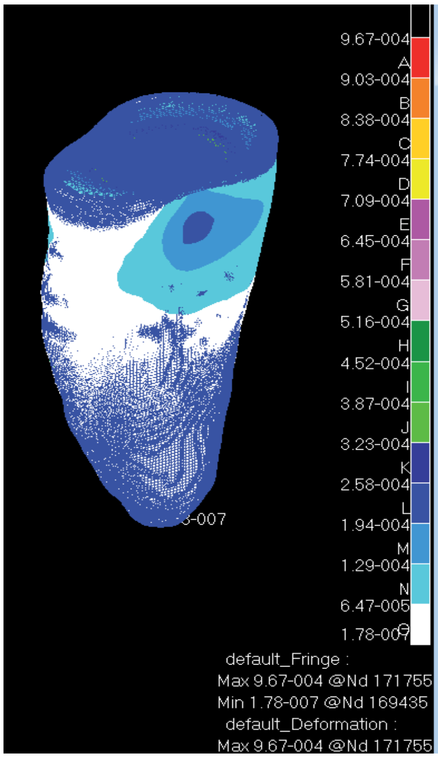

Figure 6. *Displacement under vertical loading before removal of the fractured file.*

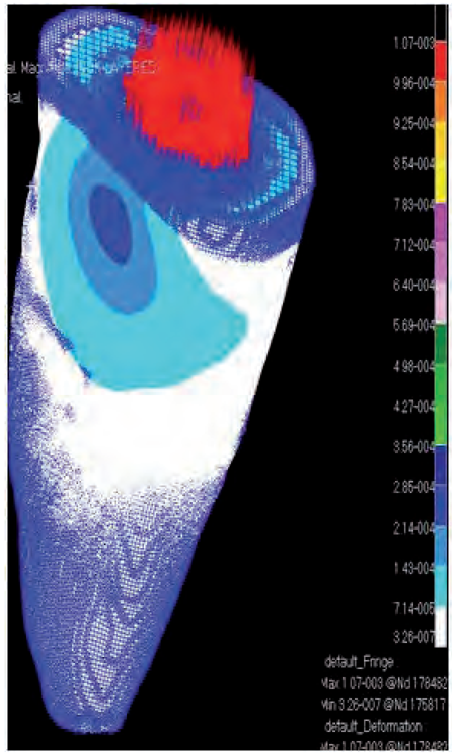

Figure 7. *Displacement under vertical loading after removal of the fractured file.*

into 3D models, is a valid research method to estimate deformation and stress distribution within tooth tissues and their restorative materials[18-19]. Root canal treatment is usually responsible for increasing stress distribution within root dentine regardless of the restoration type. However restoring the functionality of tooth structure with full coverage adhesive restorative material was found to reinforce remaining tooth structure and reduce stress concentration in critical areas, hence reduce the fracture risk [20-21].

Vertical root fracture is not an uncommon complication in endodontically-restored teeth, particularly when tooth structure is weakened by post restoration or compromised as a consequence of fractured file removal procedures[11-22]. Root cracks or fractures might not be possible to be depicted either clinically nor radiographically, especially at the very early stages before being associated with peri-radicular radiolucency. Plain intra-oral radiographs are not always useful tools to depict cracks or incomplete splits in the absence of peri-radicular radiolucency owing to their 2D limited representation. Cone-beam computed tomography (CBCT) scans can present better 3D views of small tooth sections; it still, however, suffers great limitations in imaging root cracks especially when the root canal is obturated. In addition, CBCT scanning involves high radiation dose compared with periapical radiographs. Despite this, it is the most sophisticated imagining tool, and provides better insight into the root and crown structures and their surrounding tissues than conventional radiographs [23-24].

The restorative material has been shown to have great impact on the fracture resistance of endodontically-treated teeth. Restorative materials whose modulus of elasticity are similar to dentine and have bonding properties, like composite resins, induce less stress concentration and, subsequently, higher fracture resistance [21-25]. Root morphology, canal preparation, and method of obturation are other factors which add to the overall strength of endodontically-treated teeth. It is evident that canal profile after being prepared has a significant role in stress distribution; round canals are more favourable than oval canals, like canine teeth, which may justify the higher stress concentration at the bucculoingal plane of the root canal in this investigation[26]. Vertical compaction in curved canals is more likely to induce higher stresses than lateral condensation at the apical third[13].

In heavily broken down teeth, post restorations can strengthen the remaining tooth structure[27]. Fibre posts were found to be more different from metal posts in terms of the stress distribution and fracture resistance. Luting cement, however, seems to play a key role in root fracture resistance of endodontically-treated teeth. Resin cements significantly improve the fracture resistance compared with glass ionomer or zinc phosphate cement [16]. Therefore, it is essential that in a clinical scenario, where fractured instrument removed from the apical third involves significant loss of tooth tissues, a provision of a fibre post bonded to the root dentine with a resin cement might increase root fracture resistance and shift stress concentration towards the apical, sparing most susceptible areas in the mid-coronal third.

The cross section and the post material seem to have impact on the overall strength of the root-post complex and their durability[28]. This study suggests that the oval shape of the root canal has made the stresses more concentrated into the buccolingual direction. The findings of the FEA in this investigation support the finding of previous in vitro investigations that removing fractured instrument from the apical third is not without risk. Actually, it might result in an increased risk of vertical root fracture that is most likely being initiated buccolingually across the dentine of the root[12].

In the light of the findings of this investigation, the null hypothesis has been rejected. However, despite the limitations of this computational mathematical methodology, a clinical decision as to whether to remove fractured instruments from the apical third has to outweigh the risks of reduced fracture resistance. A recently published systematic review did not show significant different clinical outcomes if a fractured instrument was left in the canal [29].

CONCLUSIONS

Notwithstanding the limitation of this study, it was concluded that the removal of a fractured endodontic file may increase the risk of vertical root fracture in an endodontically-treated canine tooth, with the fracture most likely to be initiated in the buccolingual plane.

Therefore, the decision to remove fractured endodontic files from the apical third should take into consideration the prognostic values of leaving such fractured instrument and carefully assess the complications associated with such procedure. Further work is required to include coronal tooth tissues and periodontal ligament in anterior and posterior teeth samples.

MANUFACTURERS' DETAILS

- Micro-computed tomography (μ-CT): Skyscan (Skyscan, Belgium).
- Protaper, Maillefer, Dentsply, Switzerland.
- ScanIP, ScanCAD, Simpleware, Exeter, UK
- Patran, Nastran, MScsoftware, CA, USA.

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REFERENCES

1. Shen Y, Qian W, Abtin H, Gao Y, Haapasalo M. Fatigue testing of controlled memory wire nickel-titanium rotary instruments. *J Endod.* 2011; **37**:997-1001.
2. 2- Lee MH, Versluis A, Kim BM, Lee CJ, Hur B, Kim HC. Correlation between Experimental Cyclic Fatigue Resistance and Numerical Stress Analysis for Nickel-Titanium Rotary Files. *J Endod.* 2011;**37**:1152-7.
3. Bardsley S, Peters CI, Peters OA. The effect of three rotational speed settings on torque and apical force with vortex rotary instruments in vitro. *J Endod.* 2011;**37**:860-4.
4. Wu J, Lei G, Yan M, Yu Y, Yu J, Zhang GInstrument Separation Analysis of Multi-used ProTaper Universal Rotary System during Root Canal Therapy. *J Endod.* 2011;**37**:758-63.
5. Madarati AA, Watts DC, Qualtrough AJ. Factors contributing to the separation of endodontic files. *Br Dent J.* 2008 8;**204**:241-5.
6. Suter B, Lussi A, Sequeira P.Probability of removing fractured instruments from root canals. *Int Endod J.* 2005;**38**:112-23.
7. Tzanetakis GN, Kontakiotis EG, Maurikou DV, Marzelou MP. Prevalence and management of instrument fracture in the postgraduate endodontic program at the Dental School of Athens: a five-year retrospective clinical study. *J Endo.* 2008 Jun;**34**:675-8.
8. Madarati AA, Watts DC, Qualtrough AJ. Opinions and attitudes of endodontists and general dental practitioners in the UK towards the intracanal fracture of endodontic instruments: part 1. *Int Endod J.* 2008; **41**:693-701.
9. Madarati AA, Watts DC, Qualtrough AJ. Opinions and attitudes of endodontists and general dental practitioners in the UK towards the intra-canal fracture of endodontic instruments. Part 2. *Int Endod J.* 2008; **41**:1079-87.
10. Madarati AA, Qualtrough AJ, Watts DC.Endodontists experience using ultrasonics for removal of intra-canal fractured instruments. *Int Endod J.* 2010;**43**:301-5.
11. Madarati AA, Qualtrough AJ, Watts DC. Effect of retained fractured instruments on tooth resistance to vertical fracture with or without attempt at removal. *Int Endod J.* 2010;**43**:1047-53.
12. Madarati AA, Qualtrough AJ, Watts DC. Vertical fracture resistance of roots after ultrasonic removal of fractured instruments. *Int Endod J.* 2010;**43**:424-9.
13. Cheng R, Zhou XD, Liu Z, Yang H, Gao QH, Hu T. Finite element analysis of the effects of three preparation techniques on stresses within roots having curved canals. *Int Endod J.* 2009;**42**:220-6.
14. Magne P. Efficient 3D finite element analysis of dental restorative procedures using micro-CT data. *Dent Mater.* 2007;**23**:539-48.
15. Jiang W, Bo H, Yongchun G, LongXing N. Stress distribution in molars restored with inlays or onlays with or without endodontic treatment: a three-dimensional finite element analysis. *J Prosthet Dent.* 2010;**103**:6-12
16. Soares CJ, Raposo LH, Soares PV, Santos-Filho PC, Menezes MS, Soares PB, Magalhães D. Effect of different cements on the biomechanical behavior of teeth restored with cast dowel-and-cores-in vitro and FEA analysis. *J Prosthodont.* 2010;**19**:130-7.
17. Soares CJ, Raposo LH, Soares PV, Santos-Filho PC, Menezes MS, Soares PB, Magalhães D. Effect of different cements on the biomechanical behavior of teeth restored with cast dowel-and-cores-in vitro and FEA analysis. *J Prosthodont.* 2010;**19**:130-7.
18. Magne P. Virtual prototyping of adhesively restored, endodontically treated molars. *J Prosthet Dent.* 2010;**103**:343-51.
19. Tajima K, Chen KK, Takahashi N, Noda N, Nagamatsu Y, Kakigawa HThree-dimensional finite element modeling from CT images of tooth and its validation. *Dent Mater J.* 2009;**28**:219-26.
20. Soares PV, Santos-Filho PC, Queiroz EC, Araújo TC, Campos RE, Araújo CA, SoaresCJ.Fracture resistance and stress distribution in endodontically treated maxillary premolars restored with composite resin. *J Prosthodont.* 2008;**17**:114-9.
21. Jiang W, Bo H, Yongchun G, LongXing N. Stress distribution in molars restored with inlays or onlays with or without endodontic treatment: a three-dimensional finite element analysis. *J Prosthet Dent.* 2010;**103**: 6-12.
22. Al-Omiri MK, Rayyan MR, Abu-Hammad O. Stress analysis of endodontically treated teeth restored with post-retained crowns: A finite element analysis study. *J Am Dent Assoc.* 2011;**142**:289-300.
23. Hassan B, Metska ME, Ozok AR, van der Stelt P, Wesselink PR. Detection of vertical root fractures in endodontically treated teeth by a cone beam computed tomography scan. *J Endod.* 2009;**35**:719-22.
24. Ozer SY. Detection of vertical root fractures of different thicknesses in endodontically enlarged teeth by cone beam computed tomography versus digital radiography. *J Endod.* 2010;**36**:1245-9.
25. Magne P. Efficient 3D finite elemen analysis of dental restorative procedures using micro-CT data. *Dent Mater.* 2007;**23**:539-48
26. Versluis A, Messer HH, Pintado MR. Changes in compaction stress distributions in roots resulting from canal preparation. *Int Endod J.* 2006;**39**:931-9.
27. Soares CJ, Soares PV, de Freitas Santos-Filho PC, Castro CG, Magalhaes D, Versluis A. The influence of cavity design and glass fiber posts on biomechanical behavior of endodontically treated premolars. *J Endod.* 2008;**34**:1015-9.
28. Santos AF, Tanaka CB, Lima RG, Espósito CO, Ballester RY, Braga RR, Meira JB. Vertical root fracture in upper premolars with endodontic posts: finite element analysis. *J Endod.* 2009;**35**:117-20.
29. Panitvisai P, Parunnit P, Sathorn C, Messer HH. Impact of a retained instrument on treatment outcome: a systematic review and meta-analysis. *J Endod.* 2010 May;**36**:775-80