https://doi.org/10.48047/AFJBS.6.8.2024.2752-2760

AFJBS

African Journal of Biological Sciences

Research Paper Open Access

EFFECT OF CRYOTHERAPY ON THE CYCLIC FATIGUE RESISTANCE OF ROTARY NITI FILES: A FINITE ELEMENT ANALYSIS

[1] Dr Vishnu Prasad MDS *, [2] Dr Janani Karunakaren MDS, [3] Dr Srilekha Jayakumar MDS, [4] Hari Priya Karthikeyan, [5] Dr Vashini MDS, [6] Dr Harishma MDS

* [1] Senior Lecturer, Department of Conservative Dentistry and Endodontics, Chettinad Dental College and Research Institute (Affiliated to TN MGR MEDICAL UNIVERSITY), Kelambakkam, Chennai, Tamil Nadu, India. Email: visprasad9818@gmail.com

[2] Senior Lecturer, Department of Conservative Dentistry and Endodontics, Chettinad Dental College and Research Institute (Affiliated to TN MGR MEDICAL UNIVERSITY),, Kelambakkam, Chennai, Tamil Nadu, India. Email ID: janani6694@gmail.com

[3] Reader, Department of Conservative Dentistry and Endodontics, Chettinad Dental College and Research Institute (Affiliated to TN MGR MEDICAL UNIVERSITY), Kelambakkam, Chennai, Tamil Nadu, India. Email ID: srilekhajayakumar@gmail.com

[4] Undergraduate, Sri Venkateshwaraa Dental College(Affiliated to PONDICHERRY CENTRAL UNIVERSITY), Pondicherry, India. Email ID: haripriyakarthi03@gmail.com

[5] Senior Lecturer, Department of Conservative Dentistry and Endodontics, Chettinad Dental College and Research Institute (Affiliated to TN MGR MEDICAL UNIVERSITY), Kelambakkam, Chennai, Tamil Nadu, India. Email ID: vashni.joshua@gmail.com

[6] Senior Lecturer, Department of Conservative Dentistry and Endodontics, Chettinad Dental College and Research Institute (Affiliated to TN MGR MEDICAL UNIVERSITY), Kelambakkam, Chennai, Tamil Nadu, India. Email ID: harishma2512@gmail.com

Corresponding Author: Dr Vishnu Prasad

Email ID: visprasad9818@gmail.com

Article History

Volume 6, Issue 8, 2024

Received: 09 May 2024

Accepted: 10 Jun 2024

doi: 10.48047/AFJBS.6.8.2024.2752-2760

Abstract

The use of endodontic files multiple times can cause fatigue in them and can lead to their separation in the root canal. The purpose of this study was to achieve a reduction in cyclic fatigue stress in a newly introduced nickel-titanium (NiTi) rotary single-file system. The study aimed to determine whether cryotherapy could help reduce cyclic fatigue and stress on rotary files after multiple uses during root canal treatment. By utilizing finite element analysis (FEA), the study provided a comprehensive evaluation of how cryotherapy might enhance the performance and longevity of these instruments, ultimately benefiting patients undergoing root canal therapy.

Methodology

This in vitro comparative study used scanned plastic teeth with genuine root canal anatomy and FEA to investigate the mechanical response to cyclic fatigue and stress of NiTi rotary file system. The endodontic file (TruNatomy,dentsply) was created through the complex root canal geometries, for which mandibular tooth models were scanned and created by a computer software (Abaqus). The total sample size was 34, divided into two groups, with each group comprising 17 participants (n = 17). The results were analyzed by analysis of variance (ANOVA) test.

Results

The results revealed that the p-values were less than 0.001, indicating significant reduction in cyclic fatigue when the NiTi rotary single-file system (TruNatomy,dentsply) was treated with cryotherapy . However, stress reduction was observed in the NiTi rotary single-file system when it was treated with cryotherapy.

Conclusion

This in vitro comparative study concluded that cryotherapy helps to reduce the stress of NiTi rotary singlefile system. Nonetheless, more research is needed to understand the clinical significance of the findings of the current in vitro study.

Keywords: Cryotherapy, Finite Element Analysis, Rotary Nickel Titanium files, TruNatomy

Introduction

The introduction of Nickel Titanium (NiTi) alloy in endodontic instruments has been considered a technological revolution in root canal instrumentation [1]. The introduction of NiTi alloy in rotary files has replaced traditional stainless-steel files due to its superior mechanical properties like biocompatibility, resistance to corrosion, shape memory, and super-elasticity [1,3]. These tapered files resulting in almost perfect tapered canals have considerably increased the success rates and treatment outcomes in 95% of root canal therapies [3,4]. Though NiTi files are more resistant to fractures and possess higher flexibility, resistance to bending and torsional stresses are limitations of using NiTi alloy files [5,6].

Despite its favorable properties, endodontic rotary files with NiTi alloy experience intraoperative cyclic fatigue fractures. It occurs when endodontic files are subjected to both tensile and compressive stress during rotation in curved canals resulting in intraoperative fracture signifying an iatrogenic error [7-11]. Manufacturers of rotary files focus on enhancing the mechanical capabilities to minimize procedural anecdotes of file fractures that include the incorporation of different cross-section designs of files, the introduction of heat treatment, several surface treatments including cryogenic treatment, and development of better cutting blades [10-13].

Cryogenic treatment (CT) involves exposing the instruments to very low temperatures affecting the entire thickness of the metal [12]. Though CT has been proposed to improve the microhardness, and the resistance to cyclic fatigue of NiTi files, [14] other studies had contrasting findings where CT had no significant effect on cyclic fatigue of NiTi files [15,16]. Recently, Finite Element Analysis (FEA) has been proposed to analyse the mechanical behaviour and understand the cyclic fatigue resistance of endodontic instruments subjected to dynamic and static loads [17,18]. The usage of FEA eliminates the necessity of additional expertise and advanced knowledge required to generate accurate geometrics of files either by CAD method and/or CT scanners [19]. Not many studies have been conducted to determine the cyclic fatigue resistance of a single NiTi rotary file system subjected to CT in an FEA platform.

Therefore, the present *in-vitro* study was conducted to determine stress distribution and cyclic fatigue resistance of single NiTi rotary files with a secondary objective to determine if CT helps to reduce the cyclic fatigue stress after multiple uses in a 3D constructed root canal on the FEA platform.

Materials and Methodology

The present in vitro study was conducted in the Department of Conservative Dentistry and Endodontics of a Tertiary teaching dental college in South India. The study was approved by the Institutional Ethics Committee. The study was conducted in 2022. The finite element models were designed using ABAQUS®. The designing of finite element models for simulating root canals was carried out in two steps: 1. Construction of a 3-dimensional finite element model of a rotary file, and 2. Construction of a 3-dimensional root canal model.

3-dimensional finite element model of tooth models

Five models were made using a traditional fixed taper rotary. The newly introduced NITI rotary single file system was used to instrument and shape the canals to apical sizes #20 and #30. The mandibular tooth models were scanned and created by a modelling software (FEM) (IDEAS11 NX; UGSiPlano, TX) [Figure 1]

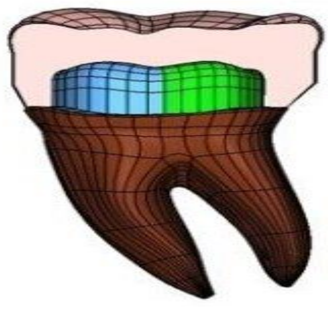

Figure 1: 3-D model of tooth

3-dimensional finite element model of rotary file

A commercially available NITI Rotary single file system (TruNatomy, Dentsply) was chosen to analyze the variation in cyclic fatigue. These groups were further subdivided according to the number of cycles of biomechanical preparation (BMP).–This endodontic file (with its distinct components: the active part, shaft, and transition part) was created by computer through the junction of two distinct geometries: the raw material and the machined material. The raw material matches the shape of an endodontic file before the cutting edges are machined over it. Its axisymmetry geometry consists of a shaft (cylindrical part) and an active part (truncated cone). The machining of blades along the length of the active part was done based on the cross-section of NITI rotary files [Figure 2]. The elements of the FE mesh are given mechanical properties during the designing phase. The elastic modulus E and the "Poisson's coefficient" v, define the elastic range of a material. The NITI alloy has Young's modulus E of 36GPa and Poisson's ratio of 0.3 [20, 21].

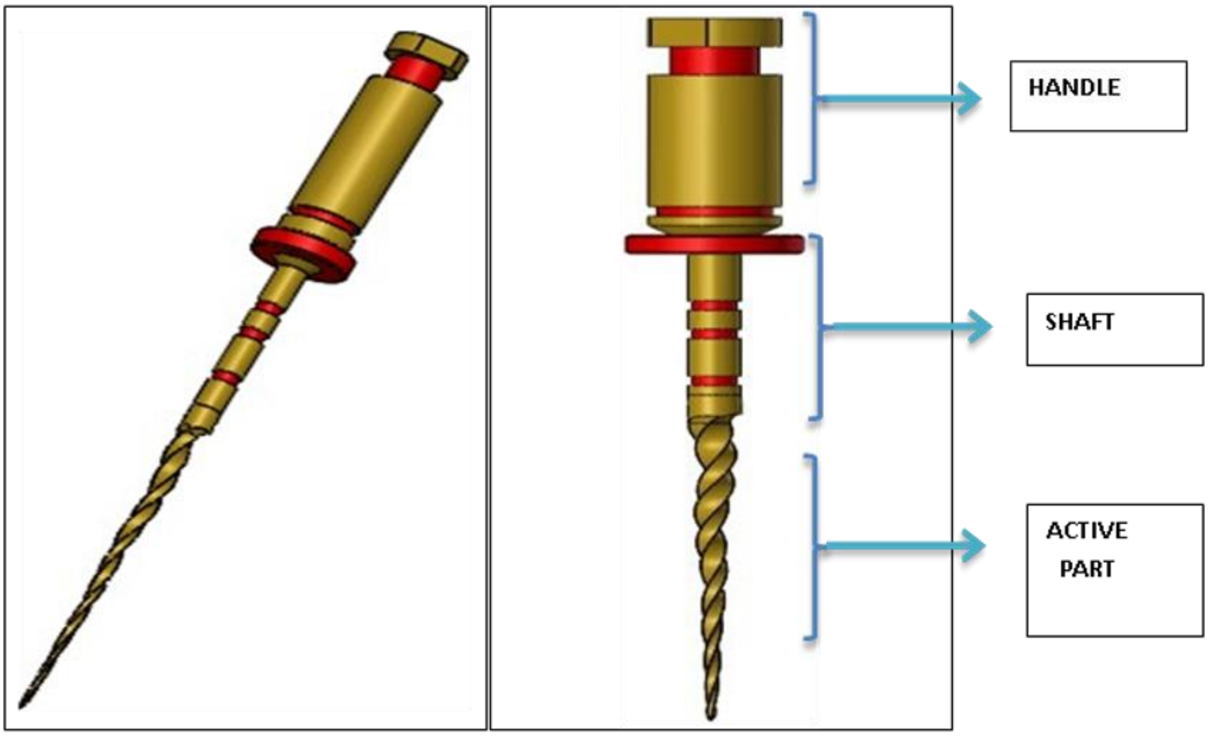

Figure 2: FEA Model of single-use rotary NiTi files

Two different load cases were created to investigate bending and torsional stresses. The FE solver receives an input file containing the whole FE model definition through this procedure. It is important to emphasize that this approach eliminates the need for extra third-party software by producing fully parameterized FE models in which the user may specify the geometry mesh density, material properties, and loading conditions. To generate a 3D model for FE analysis, a mesh of linear, eight-noded, hexahedral components was put over the instrument in the program.

The loading and boundary conditions, for the FE model, are established in the final stage. A mesh of linear, 8-noded, hexahedral components was placed over the instrument to create a 3D model for FE analysis. The z-axis was chosen to run parallel to the cross-section, i.e. along the

instrument's length.
For this study, two conditions were chosen. The FE model constructed for the study was divided into two groups based on cryogenic treatment: Group I – files subjected to cryotherapy, and Group II – files not subjected to cryotherapy. These were further subdivided according to the number of cycles of biomechanical preparation. The cryogenic behaviour of the 3-dimensional file was simulated by combining the geometry with cryogenic treatment which was obtained by subjecting NITI files to cryotherapy as per the protocols [7, 22].
Instead of only changing the metal's surface, cryotreatment can change the metal's whole cross-section. The methodology suggested by Vinothkumar was adhered to in this in vitro investigation [13]. The cryogenic liquid was turned into vapor and entered the area below the platform by a time-temperature program that cooled the samples with evaporating vapor from the cryogenic liquid pool in the area below the platform, bringing the temperature down gradually to -184.44°C (88.6 K or -300°F) at a rate of 1.5°C/min for two hours and 18 minutes. After cryogenically treating NiTi instruments, their microhardness was improved. Numerous details on the stress conditions along the file length are provided by the maximum and average stress profiles. This indicates maximum localized stress levels and the average stress in each section of NiTi rotary. In this in-vitro comparative study, instruments were spun at a constant speed of 300 rpm with a lower torque of 3 N m in this study [23].

Results

Table 1 shows that the comparison between the NITI file and the NITI-cryotreated file under fatigue conditions reveals a significant difference in performance. The NITI file endured 6.875 cycles, while the NITI-cryotreated file demonstrated almost double the endurance, completing 15.378 cycles. This data suggests that cryotreatment may enhance the durability of the NITI file, making it more resistant to fatigue.

	Number of Cycles	
	TruNatomy Files	**TruNatomy-Cryotreated Files**
Fatigue	6.875	15.378

Table 1: Number of cycles

Table 2 shows that the distribution of stress levels during the insertion of the file was statistically significantly lower in the NITI-cryotreated file (403.86 MPa) when compared to NITI files (507.732 MPa). This stress reduction suggests that the cryotreated file may offer improved resilience and better performance under bending stress than the standard NITI files.

	N	**Mean**	**SD**	**SE**	**t**	**p**
TruNatomy File	17	507.732	214.807	52.098	1.568	P = 0.127 NS
TruNatomy Cryo Treated File	17	403.876	168.646	40.903		

Table 2: Mean stress due to file insertion in root canal between the types of files

N-Number; SD-Standard deviation; NS-not significant using unpaired t-test

It was also found that there was a significant reduction in the cyclic fatigue of NITI-cryotreated (686.84 MPa) files compared to NITI files that were not cryotreated (858.3 MPa). In addition, a negative strong correlation was found between the thread length of the file and stress level during insertion for both cryotreated (r = -0.827; P = 0.001) and non-cryotreated files (r = -0.828; P = 0.001).

Discussion

NITI instruments are known for greater elastic flexibility in torsion and bending, and superior resistance to torsional fracture as compared to stainless steel files. This can be attributed to the property of shape memory and super elasticity of nickel-titanium alloy [1]. Nevertheless, these are prone to separation due to the cyclic fatigue resulting from repetitive loading and unloading applied on these files. The recently introduced single-file rotary system claims to rectify the issue by reducing stress on files and preventing separation.

Though numerous methods are available to analyze stress levels on endodontic files, FEA has been introduced as a reliable virtual testing approach to predict the mechanical behavior of NiTi files through a reverse engineering approach [24]. The principle of FEA is that any given structure is discretized into simpler elements called "Finite elements" connected through nodes. It makes it easier to study the deformation of each finite element than the for the entire undivided structure.

Cryogenic treatment (CT) has often been implemented as a cost-effective option since it improves the cutting efficiency, enhances the overall strength of the metal, and has more advantages than the standard cold treatment at greater temperatures [25]. Simulations from the present study found that the CT files endured more cycles than non-CT files, indicating enhanced durability of cryo-treated files, making them more fatigue resistance. It was also found in the present study that cryo-treated files endured a lower level of stress when compared to non-cryo-treated files indicating improved resilience and better performance under bending stress. The attribution can be explained by CT which generally affects the entire cross-section of the file thereby loading the alloy's austenitic phase and changing it to the alloy's martensitic phase at lower temperatures resulting in reduced internal stresses. Though the present study was an FEA, our results were supported by Arslan et al [26] and Zadfatah et al [27] who reported that CT enhances the fracture resistance of rotary files and improves cyclic fatigue resistance. In addition, Zasfatah also reported that cryo-treated files had significantly more number of cycles than non-cryo-treated files [27]. Though our FEA highlights enhanced properties of cryo-treated files, our results were in contrast to a study conducted by Sabat et al, who reported no significant differences between cryo-treated and untreated NiTi files [28]. These variations could be due to various factors such as different rotation speeds, physical properties, cross-sectional design of the file, and study designs.

Though our focus is primarily on the effect of CT on cyclic fatigue of NiTi files, we cannot ignore the influence of the cross-sectional design of the files on fatigue resistance [29]. Gambirini et al reported higher cyclic fatigue stress resistance in NiTi files with an S-shaped cross-section when compared to a rectangular and triangular cross-section [30]. In addition, Peters et al reported that files with triangular cross-sections had stronger fatigue resistance than files with square cross-sections [31]. The present study found a strong negative correlation between file thread length and stress during file insertion irrespective of cryo-treatment. This indicates longer the threading of the files, the lower the stress during file insertion. Furthermore, a smaller tip diameter indicates lower fatigue resistance of the file [29].

Cryogenic treatment improves the cyclic fatigue resistance of endodontic files, however, certain factors like the composition of the alloy and manufacturing process of NiTi files determine the final mechanical properties. Though Zelic et al [32] reported that the composition of NiTi alloy has no impact on its mechanical properties, it remains a challenge to identify if other linked factors have a role in the mechanical properties of NiTi files.

The present study had its limitations in, a) lack of natural root anatomy and clinical variables, b) use of simplified tooth models, c) use of only one type of single-use rotary files, d) lack of operator experience, and e) not enough information on the nickel in alloy. Based on the above limitation, the authors recommend that the results need to be extrapolated with caution.

Conclusion

Within the limitation of this in-vitro study, it can be concluded that cryotherapy helps to reduce the cyclic fatigue stress of single-use rotary NiTi files enabling its multiple usage in the root canal. However, there is a scope for further research with multiple variables that can provide us with more accurate properties of single-use rotary NiTi files.

REFERENCES

1. Walia H, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of nitinol root canal files. Journal of Endodontics 1988;14;346–351.
2. Fife D, Gambarini G, Britto LR. Cyclic fatigue testing of ProTaper NiTi rotary instruments after clinical use. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology 2004;97:251–256.
3. Brotzu A, Felli F, Lupi C, Vendittozzi C, Fantini E. Fatigue behavior of lubricated Ni-Ti endodontic rotary instruments. Frattura ed Integrità Strutturale 2014; 8:19–31.
4. Chércoles-Ruiz A, Sánchez-Torres A, Gay-Escoda C. Endodontics, Endodontic Retreatment, and Apical Surgery Versus Tooth Extraction and Implant Placement: A Systematic Review. Journal of Endodontics 2017; 43:679–686.
5. Ingle JI, Bakland LK, Baumgartner JC. Ingle`s endodontics 6th ed. Hamilton, ON: B. C. DeckerInc; 2008.
6. Di Russso FM, Zanza A, Gisario A, Natali S, Ruta G, Testarelli L. FEM analysis of NiTi rotary endodontic instruments to fatigue stress conditions: influence of geometrical parameters and design optimization. Procedia Structural Integrity 47 (2023) 765–781.
7. George GK, Sanjeev K, Sekar M. An in vitro evaluation of the effect of deep dry cryotreatment on the cutting efficiency of three rotary nickel titanium instruments. J Conserv Dent 2011; 14:169-72.
8. Ismail AG, Zaazou MHA, Galal M, Kamel NOM, Nassar MA. Finite element analysis comparing WaveOne Gold and ProTaper Next endodontic file segments subjected to bending and torsional load. Bull Natl Res Cent 2019; 43:194.
9. Kim HC, Kim HJ, Lee CJ, Kim BM, Park JK, Versluis A. Mechanical response of nickel-titanium instruments with different crosssectional designs during shaping of simulated curved canals. International Endodontic Journal 2009; 42:593–60.
10. Peters O. Current Challenges and Concepts in the Preparation of Root Canal Systems: A Review. Journal of Endodontics 2004; 30:559–567.
11. Plotino G, Grande NM, Cordaro M, Testarelli L, Gambarini GA. Review of Cyclic Fatigue Testing of Nickel-Titanium Rotary Instruments. Journal of Endodontics 2009; 35:1469–1476.

12. Mohammadi Z, Soltani MK, Shalavi S, Asgary S. A Review of the Various Surface Treatments of NiTi Instruments. Iran Endod J. 2014 Fall;9(4):235-40.
13. Gavini G, Pessoa OF, Barletta FB, Vasconcellos MA, Caldeira CL. Cyclic fatigue resistance of rotary nickel-titanium instruments submitted to nitrogen ion implantation. J Endod. 2010 Jul;36(7):1183-6.
14. George GK, Sanjeev K, Sekar M. An in vitro evaluation of the effect of deep dry cryotreatment on the cutting efficiency of three rotary nickel titanium instruments. J Conserv Dent 2011; 14:169-72.
15. Yazdizadeh M, Skini M, Hoseini Goosheh SM, Jafarzadeh M, Shamohammadi M, Rakhshan V. Effect of Deep Cryogenic Treatment on Cyclic Fatigue of Endodontic Rotary Nickel Titanium Instruments. Iran Endod J. 2017 Spring;12(2):216-219.
16. Vinothkumar TS, Miglani R, Lakshminarayananan L. Influence of deep dry cryogenic treatment on cutting efficiency and wear resistance of nickel-titanium rotary endodontic instruments. J Endod. 2007 Nov;33(11):1355-8.
17. Berutti E, Chiandussi G, Gaviglio I, Ibba A. Comparative analysis of torsional and bending stresses in two mathematical models of nickel-titanium rotary instruments: ProTaper versus ProFile. J. Endod. 2003, 29, 15–19.
18. Bonessio N, Pereira ES, Lomiento G, Arias A, Bahia MG, Buono VT, Peters OA. Validated finite element analyses of WaveOne Endodontic Instruments: A comparison between M-Wire and NiTi alloys. Int. Endod. J. 2015, 48, 441–450.
19. Bonessio N, Arias A, Lomiento G, Ove A. Peters Effect of root canal treatment procedures with a novel rotary nickel titanium instrument (TRUShape) on stress in mandibular molars: a comparative finite element analysisjournal of odontology 2016 ; 44:557-56.
20. Medha A, Patil S, Hoshing U, Bandekar S. Evaluation of forces generated on three different rotary file systems in apical third of root canal using finite element analysis. J Clin Diagn Res 2014; 8:243–6.
21. Galal M, Nassef T, Saber S, Zaazou M, El-Ashry S. Stress distribution of three Ni-Ti rotary files under bending and torsional conditions using a finite element analysis. Ain Shams Med J 2015; 1:6.
22. Vinothkumar TS, Miglani R, Lakshminaraayanan L. Influence of deep dry cryogenic treatment on cutting efficiency and wear resistance of NiTi rotary endodontic instruments. J Endod 2007; 33:1355-8.
23. Gambarini G. Cyclic fatigue of nickel-titanium rotary instruments after clinical use with low- and high-torque endodontic motors. J Endod. 2001; 27:772–4.
24. Scattina, A.; Alovisi, M.; Paolino, D.S.; Pasqualini, D.; Scotti, N.; Chiandussi, G.; Berutti, E. Prediction of Cyclic Fatigue Life of Nickel-Titanium Rotary Files by Virtual Modeling and Finite Elements Analysis. J. Endod. 2015, 41, 1867–1870.
25. Molinari A, Pellizzari M, Gialenella S, Strafellini G, Stiansky KH. Effect of deep cryogenic treatment on the mechanical properties of tool steels. Mater Process Technol. 2001; 118:350–5.
26. Arslan H, Doğanay Yildiz E, Taş G, Bayındır O, Topçuoğlu HS. The effect of cooling Reciproc instruments prior to preparation on their cyclic fatigue resistance at simulated body temperature. Turk Endod J 2021; 6:35-38.

27. Zadfatah F, Galledar S, Pourasgar Sh, Fathiazar A. Effect of cryotherapy on fracture resistance of Neoniti rotary instruments. Front Dent. 2023:20:28.
28. Sabet Y, Shahsiah S, Yazdizadeh M, Baghamorady S, Jafarzadeh M. Effect of deep cryogenic treatment on cyclic fatigue resistance of controlled memory wire nickel-titanium rotary instruments. Dent Res J 2020; 17:300-5.
29. Tang W, Wu Y, Smales RJ. Identifying and reducing risks for potential fractures in endodontically treated teeth. J Endod.2010;36:609–17.
30. Gambarini G, Grande NM, Plotino G, Somma F, Garala M, De Luca M. *etal.* Fatigue resistance of engine-driven rotary nickel-titanium instruments produced by new manufacturing methods. J Endod 2008; 34: 1003-5.
31. Peters OA, Arias A, Paque F. A micro-computed tomography assessment of the canal shaping ability of a novel rotary instrument, TRUShape, in mesial canals of mandibular molars. J Endod. 2015; 41:1545–50.
32. Zelic K, Vukicevic A, Jovicic G, Aleksandrovic S, Filipovic N,Djuric M. Mechanical weakening of devitalized teeth: three dimensional finite element analysis and prediction of tooth fracture. Int Endod J. 2015; 48:850–63.