ISSN: 2309-5288 (Print)
ISSN: 2309-6152 (Online)
CODEN: JCLMC4

Journal of Coastal Life Medicine

Comparative Evaluation of Dentinal Cracks Formation After Root Canal Preparation Using 3 Different Single-Shape Rotary Systems: TruNatomy, HyFlex EDM, And XP-endo Shaper – A Stereomicroscopic In Vitro Analysis

Received: 17 October 2022, **Revised:** 13 November 2022, **Accepted:** 15 December 2022

Dr. Priyal Shah[1]*, Dr. Kailash Attur[2], Dr. Kiran Vachhani[3], Dr. Nikunj Patel[4], Dr. Karna Jani[5], Dr. Prateek Pachore[6]

[1]Post Graduate Student, Department of Conservative Dentistry & Endodontics, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, Visnagar, Gujarat, India. priyalshah009@gmail.com, dr.priyal191195@gmail.com, 9558191195, 7600634151

[2]Professor and head, Department of Conservative Dentistry & Endodontics, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, Visnagar, Gujarat, India. atturkailash@gmail.com, 9727752499

[3]Professor, Department of Conservative Dentistry & Endodontics, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, Visnagar, Gujarat, India. dr.kiranvachhani@yahoo.com, 9825348052

[4]Reader, Department of Conservative Dentistry & Endodontics, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, Visnagar, Gujarat, India. tonikunjpatel@gmail.com, 7383798549

[5]Reader, Department of Conservative Dentistry & Endodontics, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, Visnagar, Gujarat, India. karnajani31@gmail.com, 9574443233

[6]Senior lecturer, Department of Conservative Dentistry & Endodontics, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, Visnagar, Gujarat, India. prateekjpachore@gmail.com, 8758265341

*Corresponding Author: Dr. Priyal Shah

Post Graduate Student, Department of Conservative Dentistry & Endodontics, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, Visnagar, Gujarat, India. priyalshah009@gmail.com, dr.priyal191195@gmail.com

Keywords

dentinal crack, stereomicroscope, single-shape rotary system, trunatomy, hyflex-edm, xo-endo shaper

Abstract

Background: This study is aimed to evaluate and compare the occurrence of dentinal cracks after root canal preparation with three different single-shape rotary file-systems using a stereomicroscope. Materials and Methods: Sixty extracted single rooted teeth were selected and divided into three experimental groups and a negative control group of 15 each. The canals were prepared in the experimental groups. Group I - TruNatomy, Group II - HyFlex EDM, Group III - XP-endo Shaper. No preparation was done in the control group (Group IV). The roots were sectioned at 3, 6, and 9 mm from the root apex, and the surfaces were examined under a stereomicroscope. The data were analyzed using the Chi-square, and Fisher's Exact tests. Results: No cracks were seen in the control group. XP endo shaper files showed significantly fewer cracks ($P > 0.05$) at 3, 6, and 9 mm. No significant difference was observed among TruNatomy and XP endo shaper groups at 6 mm ($P > 0.05$). The HyFlex EDM files produced higher cracks when compared with the other groups ($P > 0.05$) at 3, and 9 mm. Statistically, no significant difference was present in dental crack scores among various groups at coronal, middle, and apical portions. Conclusion: All rotary instruments cause dentinal microcracks; with increased frequency in the apical root dentin. XPS caused significantly less dentinal damage than TRN and HEDM systems. TRN caused fewer microcracks than HEDM in the coronal and apical thirds.

ISSN: 2309-5288 (Print)
ISSN: 2309-6152 (Online)
CODEN: JCLMC4
Journal of Coastal Life Medicine

1. Introduction

The main objective of chemo-mechanical root canal preparation is to completely remove the microorganisms, debris, and organic tissue by enlarging the root canal diameter to create the canal space for receiving an obturating material.[1,2] However, various procedural errors such as perforations, canal transportation, ledge formation, canal zipping, instrument fracture, and dentinal crack formation may occur during root canal preparation.[3]

During biomechanical root canal preparation, stress concentration that originates from the contact of the endodontic instrument with the dentin may induce dentinal crack formation, which under repetitive occlusal forces propagates to turn vertical root fracture. A vertical root fracture is a disastrous problem of root canal treatment caused by the propagation of smaller and less pronounced dentinal defects. Consequently, the essential objective in endodontic research is to overcome the potential problem of dentinal crack formation during instrumentation with rotary instruments.[1,4]

One of the crucial developments in endodontic instruments has been the replacement of stainless steel (SS) with a nickel-titanium (Ni-Ti) alloy.[5] when compared to stainless steel instruments, Ni-Ti instruments have increased flexibility and short working time as a major advantage.[6] Different generations of Ni-Ti engine-driven instruments were found to differ from one another in parameters such as cutting blade design, taper and tip configuration, and alloy treatment. Although Ni-Ti instruments are clinically preferable over hand instruments, the impact of cutting blade design is still controversial and could produce more friction and stresses within the root canal.[1,7]

TruNatomy instruments (TRN) (Dentsply Sirona) has been developed as a novel type of heat-treated NiTi instrument manufactured from a 0.8 mm maximum flute diameter (MFD) NiTi wire rather than 1.2 mm NiTi wire, with a unique design. It had been reported that the TRN instruments preserve the structural dentine and tooth integrity due to instrument geometry, regressive tapers, and the slim design, accompanying the heat-treatment of the NiTi alloy.[8] HyFlex EDM (HEDM; Coltene/Whaledent, Switzerland) files are manufactured via electro-discharge machining technology using controlled memory alloy and have continuous rotation motion and remarkably enhanced mechanical properties. HEDM (25/~) files have a constant taper of 8% in the apical 4 mm; the taper decreases to 4% toward the coronal region with 3 different horizontal cross-sections all through the entire working part of the instrument.[9,10] XP-endo Shaper (XPS; FKG Dentaire, La Chaux-de-Fond, Switzerland) file has high flexibility and fatigue resistance because of the use of the MaxWire (Martensite-Austenite Electropolishing-Flex, FKG Dentaire) alloy. The design of XPS allows the instrument to adapt the root canal 3-dimensionally at body temperature via its snake-shaped motion, which expands or contracts according to the morphology of the root canal to improve cleaning and shaping. As stated by the manufacturer, high-speed operation with minimum torque also creates minimal stress on the dentinal walls.[11]

Thus, the purpose of this study was to evaluate which among the following file systems: (1) TruNatomy, (2) HyFlex EDM, and (3) XP-endo Shaper - causes minimal crack formation in coronal, middle, and apical thirds. The null hypothesis is that there would be no difference in dentinal crack formation among the groups and coronal, middle, and apical third regions.

2. Materials and Method

Extracted human permanent maxillary and mandibular; single-rooted teeth with closed apices were selected and cleaned with a periodontal scaler to remove any soft-tissue debris. Samples were then disinfected with 0.1% thymol solution, and stored in phosphate-buffered saline (PBS) until use. Radiographs were taken from mesiodistal and buccolingual aspects of the teeth before use. Teeth having root fractures, dentinal cracks, open apices, curved root canals, multiple roots, dental caries or restorations, severe anatomic variations, calcified canals, and internal or external resorption were excluded.

Teeth were decoronated using a diamond disc (Addler, Golden Nimbus, Mumbai, India) under water cooling at 15 mm from the root-apex and then all the samples were inspected under a

ISSN: 2309-5288 (Print)
ISSN: 2309-6152 (Online)
CODEN: JCLMC4
Journal of Coastal Life Medicine

stereomicroscope (Labomed, LB-340 Zoom, Los Angeles, U.S.A) with 20x to exclude external defects or cracks. A total of 60 teeth with single patent canals were selected.

Root canal preparation

The patency of the root canals was confirmed with a size #10 K-file (Mani Co, Tokyo, Japan), and the working lengths were determined as 0.5 mm short of the root apex. A glide path was prepared using size #15 K-file (Mani Co, Tokyo, Japan).

Periodontal ligament (PDL) simulation was done using polyvinylsiloxane impression material (Dentsply). Teeth were immersed into molten wax to achieve 0.2 to 0.3 mm thick layer of wax all around the root and were mounted in self-cure acrylic resin. Once the resin was set, the teeth were retrieved and the wax was scraped off from the root surfaces. The space created by the molten wax was filled with impression material to simulate PDL.

60 teeth were randomly allotted into three experimental groups and one negative control group (n = 15) based on different single-shape rotary files used for preparation. Group I - TruNatomy, Group II - HyFlex EDM, Group III - XP-endo Shaper, and Group IV – Negative Control group.

The root canals were prepared with gentle in-and-out motion using an endomotor (X-SMART, Dentsply Maillefer) with torque and speed (1.5 Newton, 500 rpm for TruNatomy; 2.5 Ncm, 400 rpm for HyFlex EDM; 1 Ncm, 800 rpm for XP-endo Shaper) as recommended by the manufacturer.

In the instrumentation sequence of Group-I (TruNatomy), orifice modifier (20/08 v), glider (17/02, with a regressive variable taper), single shaping file according to need: small (Yellow – 20/04 v) / prime (Red – 26/04 v) / medium (Green – 36/03 v) instruments were used. Orifice opener (25/12) followed by glide path file (10/05), and HyFlex One file (25/~) were used in the sequence for Group-II (HyFlex EDM). In Group-III (XP-endo Shaper), XPS (30/01) single shaping file was used. Each file was used for the instrumentation of 5 canals (or teeth). A complete rotation with light pecking in and out motion was done for instrumentation. No preparation was done in the control group.

The root canals were irrigated with 2 mL of 3% sodium hypochlorite (Vishal Dentocare Pvt. Ltd, India), 5 mL of saline (Eurolife, Pirmeera Healthcare Pvt. Ltd, Pune, India), and 5 mL of 17% ethylene diamine tetra-acetic acid (Prime Dental, India) between each instrument change, then the final rinse was done using 2 mL of distilled water.

Evaluation of Dentinal crack

The samples were stained with methylene blue (0.5%) for 24 hours and washed in running water and then washed with distilled water. All the samples were sectioned perpendicularly to the long axis of the teeth at 3 mm (apical), 6 mm (middle), and 9 mm (coronal) from the apex of the root using a diamond disc under water cooling. The slices were viewed under a stereomicroscope (x20 magnification). For the analysis, the number and extent of the cracks were counted.

The defect (any lines, microcracks, or fractures) originating from the inner root canal space and propagating to the periphery are considered as cracks. All other defects that did not originate from the canal wall, such as craze lines were not considered as cracks. Assessment of the extent of cracks (caused by instrumentation) was as followed: Score 0: No defect (Absence of any cracks or lines on the internal or external surface of the root dentin); Score 1: Incomplete crack (A line progressed into the dentin from the internal surface (canal wall) and not reached the opposing surface); Score 2: Complete crack (A line progressed to the root's outer surface from the internal surface of the canal wall).

Statistical analysis

The data was tabulated on an excel sheet (MS Office 2010) and analyzed using SPSS version 20.0. Chi-square, and Fisher's Exact statistical tests were done. The result showing P *value* ≤ 0.05 is considered statistically significant.

3. Results

No cracks were seen in the control group, at 3, 6, and 9mm. XP endo shaper files were associated with significantly fewer cracks when compared with the other groups ($P > 0.05$) at 3, 6, and 9 mm. No significant difference was observed among

ISSN: 2309-5288 (Print)
ISSN: 2309-6152 (Online)
CODEN: JCLMC4
Journal of Coastal Life Medicine

TruNatomy and XP endo shaper groups at 6 mm (P > 0.05). The HyFlex EDM files produced higher cracks when compared with the other groups (P > 0.05) at 3, and 9 mm.

Statistically, no significant difference was present in dental crack score among various groups at coronal, middle, and apical portions.

Table 1: Dental cracks-wise distribution among groups in coronal (9mm), middle (6mm), apical (3mm) thirds.

Portion	Score	Groups n (%)				P Value
		TruNatomy	HyFlex EDM	XP-endo Shaper	Control group	
9mm Coronal	No defect	14(93.3)	13(86.7)	15(100)	15(100)	> 0.05**
	Incomplete crack	1(6.7)	2(13.3)	0(0)	0(0)	
	Complete crack	0(0)	0(0)	0(0)	0(0)	
	Total	15	15	15	15	
6mm Middle	No defect	12(80)	12(80)	14(93.3)	15(100)	> 0.05**
	Incomplete crack	3(20)	2(13.3)	1(6.7)	0(0)	
	Complete crack	0(0)	1(6.7)	0(0)	0(0)	
	Total	15	15	15	15	
3mm Apical	No defect	12(80)	11(73.3)	13(86.7)	15(100)	> 0.05**
	Incomplete crack	3(20)	3(20)	2(13.3)	0(0)	
	Complete crack	0(0)	1(6.7)	0(0)	0(0)	
	Total	15	15	15	15	

Level of Significance P ≤ 0.05, * Significant, ** Non-Significant

4. Discussion

In this study, the effect of three single file systems of the 5th Generation: TruNatomy, HyFlex EDM, and XP-endo Shaper - on dentinal microcrack formation was compared. All the systems assessed in the study induced dentinal microcracks, and these findings are in concurrence with earlier studies,[1,2,3] that reported the likely correlation between the design of NiTi rotary instruments and the development of dentinal defects. In consonance with this study, all the experimental groups showed dentinal microcracks, and no cracks were observed in the control group. Thus, the null hypothesis was rejected.

Freshly extracted permanent maxillary and mandibular single-rooted teeth were used in this study to lessen their interference with the outcome of dentinal microcrack formation. Disinfection of teeth was done using 0.1% thymol solution and eventually kept in phosphate buffered saline (PBS) to prevent dehydration of extracted teeth, as it can affect dentinal crack formation.[1,2,12] According to

ISSN: 2309-5288 (Print)
ISSN: 2309-6152 (Online)
CODEN: JCLMC4
Journal of Coastal Life Medicine

Shemesh et al., 2018 the dehydration of extracted teeth induces stress which is apt to produce spontaneous cracking of dentin. In addition, inhomogeneous shrinkage of dentin has been noticed upon drying giving rise to internal stresses, According to Tatchev et al., 2022.[13]

The samples of the present study were sectioned with a diamond disc under water cooling. The sectioning of roots is a widely used method to evaluate dentinal defects. Numerous studies have used this method and revealed that the control group sections were devoid of cracks, so concluded that defects were the result of different instrumentation techniques.[14]

Self-care acrylic resin and polyvinylsiloxane impression material were used to mimic jaw-bone and periodontal ligament, respectively. Stimulation of the periodontal ligament serves as a stress absorber during instrumentation, thereby better resembling the clinical situation.[1,12]

3% NaOCl was preferred over 5.25% NaOCl as an irrigation solution as at higher concentrations, NaOCl significantly reduces the elastic modulus and flexural strength of dentin.

In this study, all the specimens were sectioned at different levels for the evaluation of dentinal cracks. Sectioning of specimens can induce dentinal cracks; thus 0.5% methylene blue dye was used post instrumentation, before sectioning, to differentiate the dentinal microcracks generated by instrumentation and sectioning of teeth;[2] as its molecular size is too small (120 nm), to penetrate more enormously than any other dyes.[1]

More cracks were observed in the apical third section of TruNatomy, and HyFlex EDM groups than in the middle, and coronal sections, which is in accordance with earlier studies conducted by Karataş *et al*.,[3] Nishad and Shivamurthy,[15] and Chole *et al*.[16] Stress distribution due to consecutive instrumentation, and low potential of the thin and fragile dentin in the apical third region to the mechanical stress generated by direct contact with the instrument's tip, may induce the formation of dentinal microcracks.[1,6]

As stated by Yoldas et al. (2012)[17], Mandava J et al. (2018)[18]: Tip design, cross-sectional geometry, pitch, taper, flute, speed, torque and rake angle of endodontic rotary instruments could affect dentinal crack formation. Greater tapered instruments credibly generate more stress on root canal walls (constant or variable).[1,17,19] However, in this study, there were no significant differences present between the TruNatomy, HyFlex EDM, and XP-endo Shaper in dentinal microcrack formation, as the TruNatomy shaping file has an overall regressive taper that averages at 0.04; HyFlex EDM shaping file has a variable taper, and XP-endo Shaper has the ability to increase the taper from .01 to at least .04. using only single instrument.[8,10,20] The design of the cross-section of the endodontic instrument can affect the number of times that it touches the root canal dentin, producing the potential to cause different degrees of tension. More contact of an endodontic instrument with the root canal walls, the more it can cause dentinal defects.[2] Kim et al. (2010) observed the likely relationship between the design of NiTi instruments and the occurrence of vertical root fractures. They observed that higher stress concentration, which increases the risk of dentinal defects, varies with instrument design.[3] It is hypothesized that another aspect that decreases the occurrence of stress on dentinal walls is the flexibility of the endodontic instrument that is provided by the heat treatment of the NiTi alloys. However, flexibility can be affected by the design of the endodontic instrument.[2] The complexity of root canal anatomy, remaining dentinal wall thickness and canal diameter after preparation, may also influence the stress concentration. In addition, the age-related change in the microstructure of dentin leading to progressive dentinal sclerosis may correspond to lower resistance to damage initiation and propagation.[21]

The new XP system is manufactured for shaping the 3-dimensional shaping deformities of root canals. According to the manufacturer, the file is prefabricated using the NiTi Max Wire (Martensite-Austenite electropolish-flex) (FKG Dentaire). The metallurgical alloy and snake-shaped design offered high flexibility to the instrument even at a high rotational speed (i.e., 800 rpm). XPS instruments have only a 1% taper, but the taper can be increased up to 4% during root canal shaping (Uslu et al., 2018). The smaller taper of XPS instruments can render file flexibility and less dentinal stress.[19,22] In

ISSN: 2309-5288 (Print)
ISSN: 2309-6152 (Online)
CODEN: JCLMC4
Journal of Coastal Life Medicine

accordance with this, XPS caused significantly less dentinal damage than TRN and HEDM systems.

Among the tested single file systems, HyFlex EDM (Coltène-Whaledent, Switzerland) has shown increased post-instrumentation dentinal defects. HyFlex EDM Shaping files are produced by control memory treatment just like Hyflex CM files. EDM process created a rough and hard surface that could improve the cutting efficiency of these files. These files have a tip size of 25 and 0.08 taper contrast. The taper is constant in the apical 4 mm of the instrument but reduces progressively up to 0.04 in the coronal portion. It has 3 different (rectangular in the apical part and two different trapezoidal cross-sections in the middle and coronal part) cross-sectional zones over the entire working length of the endodontic instrument to increase fracture resistance and cutting efficiency of the instrument. This design characteristic might cause a screwing effect and a dangerous taper lock can increase the contact between the instrument and the dentinal wall causing the formation of dentinal defects.[10,18]

TRN is manufactured from 0.8 mm NiTi wire, offset parallelogram cross-section which increases the instrument's flexibility and resistance to cyclic fatigue. This can represent the instrument's geometry, i.e., off-centered parallelogram cross-section, regressive tapers, and slim design of the instrument. Due to standardised design of TRN instruments, they are less destructive for root canal shaping due to their regressive tapers and the heat treatment of the NiTi alloy.[23] In accordance with this, the TRN instrument has generated comparatively lesser microcracks than HEDM. However, there is no significant difference between both groups in terms of dentinal crack formation.

A stereomicroscope over micro-computed tomography (CT), was used for comparative evaluation of dentinal cracks as micro-CT provides hundreds of slices, which are not easy to evaluate, and also some microcracks may be overlooked.[1]

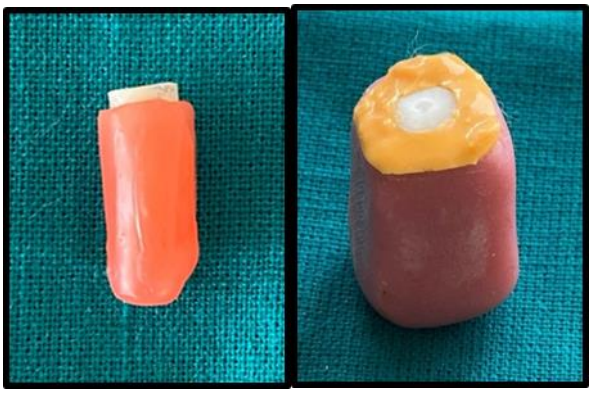

Figure 1: Periodontal ligament (PDL) and Bone stimulation

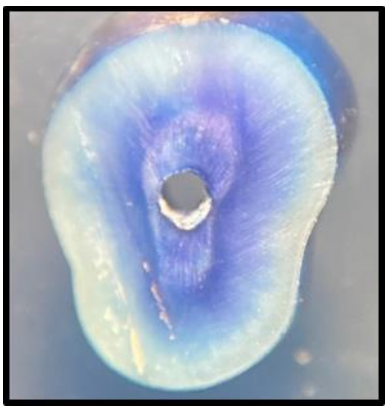

Figure 2: No defect

ISSN: 2309-5288 (Print)
ISSN: 2309-6152 (Online)
CODEN: JCLMC4
Journal of Coastal Life Medicine

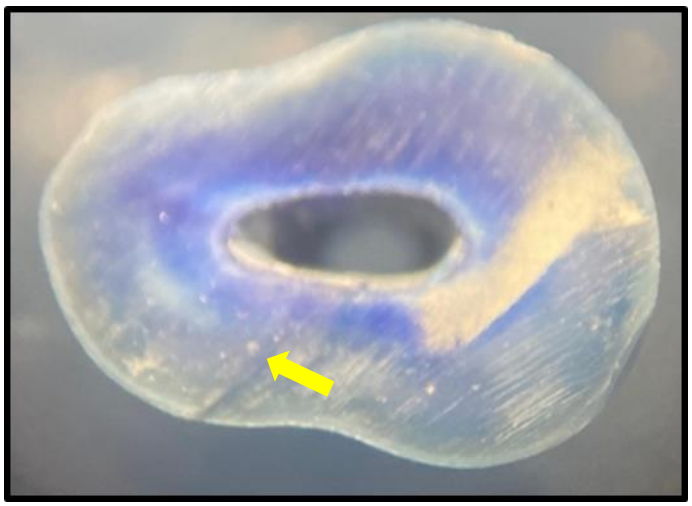

Figure 3: Complete crack

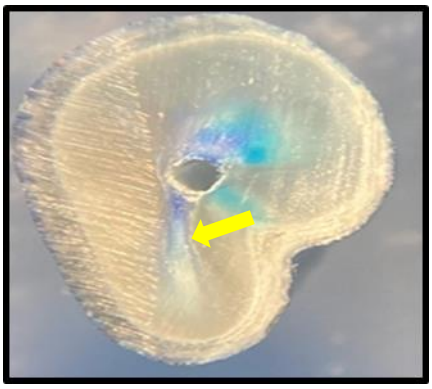

Figure 4: Incomplete crack formed by Instrumentation

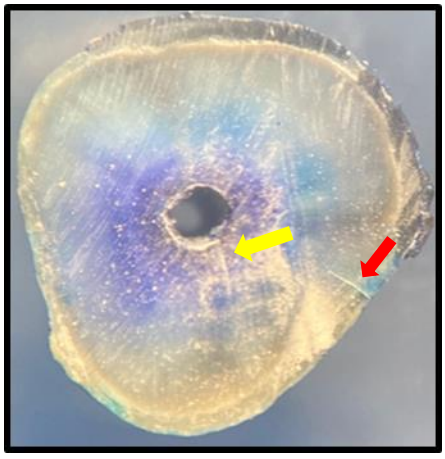

Figure 5: (Yellow arrow) Incomplete crack formed by Instrumentation (Red arrow) Incomplete crack not formed by Instrumentation

5. Conclusion

In the present in vitro study, it was concluded that XPS caused significantly less dentinal damage than TRN and HEDM systems. Furthermore, TRN caused fewer microcracks than HEDM in coronal and apical third, but there was no significant difference among the groups. Moreover, all rotary instruments cause dentinal microcracks; with increased frequency in the apical root dentin

ISSN: 2309-5288 (Print)
ISSN: 2309-6152 (Online)
CODEN: JCLMC4
Journal of Coastal Life Medicine

compared to the middle and coronal sections. This can be due to thin and less dentine thickness to counteract the lateral stresses generated by instrumentation.

CONFLICT OF INTERESTS

The authors stated that there is no conflict of interests with regard to this publication.

FINANCIAL SUPPORT AND SPONSORSHIP

None.

References

1. Soujanya E, Verma N, Kaushik M, Nagamaheshwari X, Mehra N, Prasad LK. Effect of three different rotary file systems on dentinal crack formation–A stereomicroscopic analysis. Endod. 2020 Oct 1;32(4):220.
2. Cassimiro M, Romeiro K, Gominho L, de Almeida A, Silva L, Albuquerque D. Effects of reciproc, protaper next and waveone gold on root canal walls: a stereomicroscope Analysis. Iran. Endod. J. 2018;13(2):228.
3. Karataş E, Gündüz HA, Kırıcı DÖ, Arslan H. Incidence of dentinal cracks after root canal preparation with ProTaper Gold, Profile Vortex, F360, Reciproc and ProTaper Universal instruments. Int. Endod. J. 2016 Sep;49(9):905-10.
4. Khasnis SA, Kidiyoor KH, Patil AB, Kenganal SB. Vertical root fractures and their management. J. Conserv. Dent.: JCD. 2014 Mar;17(2):103.
5. Gambarini G. Cyclic fatigue of ProFile rotary instruments after prolonged clinical use. Int. Endod. J. 2001 Jul;34(5):386-9.
6. Langaliya AK, Kothari AK, Surti NR, Patel AR, Doshi PR, Pandya DJ. In vitro comparative evaluation of dentinal microcracks formation during root canal preparation by different nickel-titanium file systems. Saudi Endod J. 2018 Sep 1;8(3):183.
7. Bier CA, Shemesh H, Tanomaru-Filho M, Wesselink PR, Wu MK. The ability of different nickel-titanium rotary instruments to induce dentinal damage during canal preparation. J. Endod. 2009 Feb 1;35(2):236-8.
8. Elnaghy AM, Elsaka SE, Mandorah AO. In vitro comparison of cyclic fatigue resistance of TruNatomy in single and double curvature canals compared with different nickel-titanium rotary instruments. BMC Oral Health. 2020 Dec;20(1):1-8.
9. Iacono F, Pirani C, Generali L, Bolelli G, Sassatelli P, Lusvarghi L, Gandolfi MG, Giorgini L, Prati C. Structural analysis of HyFlex EDM instruments. Int. Endod. J. 2017 Mar;50(3):303-13.
10. Gündoğar M, Özyürek T. Cyclic fatigue resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc Blue nickel-titanium instruments. J. Endod. 2017 Jul 1;43(7):1192-6.
11. Keskin C, Inan U, Guler DH, Kalyoncuoğlu E. Cyclic fatigue resistance of XP-Endo Shaper, K3XF, and ProTaper Gold nickel-titanium instruments. J. Endod. 2018 Jul 1;44(7):1164-7.
12. Pedullà E, Genovesi F, Rapisarda S, La Rosa GR, Grande NM, Plotino G, Adorno CG. Effects of 6 single-file systems on dentinal crack formation. J. Endod. 2017 Mar 1;43(3):456-61.
13. Shemesh H, Lindtner T, Portoles CA, Zaslansky P. Dehydration induces cracking in root dentin irrespective of instrumentation: a two-dimensional and three-dimensional study. J Endod. 2018 Jan 1;44(1):120-5.
14. Topçuoğlu HS, Demirbuga S, Tuncay Ö, Pala K, Arslan H, Karataş E. The effects of Mtwo, R-Endo, and D-RaCe retreatment instruments on the incidence of dentinal defects during the removal of root canal filling material. J. Endod. 2014 Feb 1;40(2):266-70.
15. Nishad SV, Shivamurthy GB. Comparative analysis of apical root crack propagation after root canal preparation at different instrumentation lengths using ProTaper universal, ProTaper next and ProTaper gold rotary files: an in vitro study. Contemp. Clin. Dent. 2018 Jun;9(Suppl 1):S34-S38.
16. Chole D, Kamble S, Bakle S, Gandhi N, Hatte N, Bawa P. Effects of 3 Single-File System (Protaper Universal, Protaper Next, Protaper Gold) on crack formation in dentin after root canal preparation-An in vitro study. IOSR-JDMS. 2019;18:47-50.
17. Yoldas O, Yilmaz S, Atakan G, Kuden C, Kasan Z. Dentinal microcrack formation

ISSN: 2309-5288 (Print)
ISSN: 2309-6152 (Online)
CODEN: JCLMC4
Journal of Coastal Life Medicine

during root canal preparations by different NiTi rotary instruments and the self-adjusting file. J. Endod. 2012 Feb 1;38(2):232-5.

18. Mandava J, Yelisela RK, Arikatla SK, Ravi RC. Micro-computed tomographic evaluation of dentinal defects after root canal preparation with hyflex edm and vortex blue rotary systems. J Clin Exp Dent. 2018 Sep;10(9):e844-e851.
19. Uğur Aydın Z, Keskin NB, Özyürek T. Effect of Reciproc blue, XP-endo shaper, and WaveOne gold instruments on dentinal microcrack formation: A micro-computed tomographic evaluation. Microsc Res Tech. 2019 Jun;82(6):856-60.
20. Jain A, Nikhil V, Bansal P. Effect of root canal preparation, obturation, and retreatment on the induction of dentinal microcracks: A microcomputed tomography study. J Conserv Dent. 2018 Sep;21(5):521-525.
21. Saha SG, Vijaywargiya N, Saxena D, Saha MK, Bharadwaj A, Dubey S. Evaluation of the incidence of microcracks caused by Mtwo and ProTaper Next rotary file systems versus the self-adjusting file: A scanning electron microscopic study. J Conserv Dent. 2017 Sep;20(5):355-359.
22. Keskin C, Inan U, Guler DH, Kalyoncuoğlu E. Cyclic fatigue resistance of XP-Endo Shaper, K3XF, and ProTaper Gold nickel-titanium instruments. J. Endod. 2018 Jul 1;44(7):1164-7.
23. Çirakoglu NN, Özbay Y. Evaluation of apical crack formation associated with root canal preparation with ProTaper Next, ProTaper Gold, and TruNatomy systems. Endod. 2021 Oct 1;33(4):191-195