

Incidence of Dentinal Cracks in Root Surface by Different Ni–Ti Rotary File Systems

Hisham M Elnazzer¹, Dalia A Sherif², Ahmed H Labib³

ABSTRACT

Aim and objective: Evaluating dentinal cracks in root canal surface after biomechanical preparation using rotary file systems such as ProTaper Next, 2 Shape, and RaCe.

Materials and methods: Forty extracted human single canal mandibular premolars were decoronated perpendicular to the long axis of the tooth leaving roots (12 ± 1 mm) and then positioned centrally in a mold using acrylic resin. Roots were randomly divided into four main groups ($n = 10$) according to the nickel-titanium (Ni–Ti) rotary file system used in preparation as follows: **Group I:** Control group roots were left unprepared. **Group II:** Canals were prepared using Ni–Ti 2 Shape system up to TS2 file (#25/0.06). **Group III:** Canals were prepared using Ni–Ti ProTaper Next system up to X2 file (#25/0.06). **Group IV:** Canals were prepared using Ni–Ti RaCe system up to file (#25/0.06). Each root was sectioned horizontally using IsoMet saw into three sections as coronal, middle, and apical with a total of 120 sections and observed by stereomicroscope and scanning electron microscope to detect dentinal cracks.

Results: There are more dentinal cracks in the ProTaper Next group than in the 2 Shape, RaCe, and control groups as there was a statistically significant difference present ($p < 0.05$). There was no statistically significant difference between the apical, middle, and coronal sections ($p = 0.536$).

Conclusion: ProTaper Next group showed a high percentage of dentinal crack incidence followed by RaCe, 2 Shape, and control groups regardless of the root canal cross-section, and the highest percentage of dentinal crack incidence was in the apical third followed by middle and coronal thirds regardless of the Ni–Ti system.

Clinical significance: To evaluate Ni–Ti rotary system effect on dentinal crack incidence.

Keywords: 2 Shape, Dentinal cracks, Nickel-Titanium, ProTaper Next, RaCe.

Journal of Operative Dentistry and Endodontics (2020): 10.5005/jp-journals-10047-0094

INTRODUCTION

The aim of endodontic treatment is to completely remove microorganisms, pulp tissue, and debris and achieve a three-dimensional seal for the root canal system by enlarging the diameter of the original canal anatomy to a more desirable canal shape to obtain a proper coronal and apical seal.¹

When biomechanical preparations are carried out, endodontic instruments do not act on the entire canal wall, but rather they act only on the central body of the root canal.² An instrumentation alone could produce dentinal damage in the apical region, which in turn makes the risk of crack initiation, and there is a higher incidence of production of dentinal cracks when larger files are used in root canal preparation.³ The more the amount of dentin removed, the more there is incidence for root fracture by the formation of more small craze lines that will later propagate to vertical root fracture if the tooth is subjected to repeated stresses from endodontic or restorative procedures.⁴

In the last decade, there is a huge advancement in Ni–Ti rotary systems with various files differing in their design features such as cross-section, flute depth, and rake angle. Therefore, these variables may affect dentin removal in the biomechanical preparation leading to cleaning and shaping mishaps as different craze line formation and crack generation.⁵

Defect is referred as the presence of craze line or microcracks or even complete crack that extends from the inner root canal space all the way to the outer surface of the root.⁵ So, in order to minimize the dentinal cracks and other mishaps during root

¹Department of Endodontics, Delta University for Science and Technology, Mansoura, Dakahlyia, Egypt

^{2,3}Department of Endodontics, Tanta University, Tanta, Gharbia, Egypt

Corresponding Author: Hisham M Elnazzer, Department of Endodontics, Delta University for Science and Technology, Mansoura, Dakahlyia, Egypt, Phone: +01067122559, e-mail: h_max24@live.com

How to cite this article: Elnazzer HM, Sherif DA, Labib AH. Incidence of Dentinal Cracks in Root Surface by Different Ni–Ti Rotary File Systems. *J Oper Dent Endod* 2020;5(2): 63–68.

Source of support: Nil

Conflict of interest: None

canal instrumentation, different Ni–Ti rotary systems are always introduced and developed to improve the efficiency and clinical outcomes of the root canal treatment.⁶

There are various methods to detect dentinal cracks such as micro-CT, optical coherence tomography, and vibro-infrared, but stereomicroscope and scanning electron microscope (SEM) are preferred in direct visual detection of cracks unlike other methods.⁷

MATERIALS AND METHODS

Forty freshly extracted, nearly straight, mature human mandibular premolars with single root canals were collected. Approval for this research was obtained from the Faculty of Dentistry, Tanta University, Research Ethics Committee. The purpose of the present

study was explained to the patients, and informed consents were obtained to use their teeth in the research according to the guidelines of human research published by the Research Ethics Committee at Faculty of Dentistry, Tanta University.

All collected teeth were rinsed in tap water and cleaned from soft tissues and calculus using a hand periodontal curette and stored in 10% buffered formalin phosphate solution at room temperature until used.⁸

All teeth were decoronated perpendicular to the long axis of the tooth by using a low-speed diamond disc (Dica, Dendia, United States) under a copious amount of water coolant system, leaving roots approximately 12 ± 1 mm in length to ensure standardized root length for all samples.⁹ Blocks were made using a 5-mL plastic polyvinyl syringe with 15 mm length and internal diameter 10 mm, which will act as a mold to hold the roots in it. The coronal surfaces of the roots were fixed onto a glass slap using a sticky wax for stability and centralization of the roots within the block without any root inclination.

Canal patency was established by using hand K-type stainless steel (#10/0.02) (#15/0.02) files till the full working length (WL) and then 1 mL was shortened to the final WL; radiograph was taken to verify it to ensure complete patency and to standardize the initial canal diameter.¹⁰ Then, roots were randomly divided into four groups ($n = 10$) according to the Ni-Ti rotary file system being used in root canal preparation as follows:

- **Group I (control group):** Ten root canals were left unprepared by any rotary file to serve as a control group.¹¹
- **Group II (2 Shape group):** Root canals were prepared by 2 Shape (Micro Mega™, Besancon, France) system at 350 rpm and torque at 2 N cm, respectively, according to the manufacturer's instructions in the crown down manner by first introducing TS1 Ni-Ti file (#25/0.04) to shape the coronal two-thirds, and then TS2 Ni-Ti file (#25/0.06) was carried to the full WL until the file passively reaches the apical limit.
- **Group III (ProTaper Next):** Root canals were prepared by ProTaper Next (Dentsply™ Mallefer; Ballaigues, Germany) system at 300 rpm and torque at 4 N cm, respectively, in the crown down manner by first introducing SX Ni-Ti file (#19/0.04) to shape the coronal two-thirds then X1 file (#17/0.04) and X2 file (#25/0.06) to the full WL.
- **Group IV (RaCe):** Root canals were prepared by RaCe (FKG™ Dentaire, La Chaux-de-Fonds, Switzerland) system at 600 rpm and torque at 1.5 N cm, respectively, in the crown down manner by first introducing files in the following sequence (#15/0.04), (#20/0.04), (#25/0.04), (#25/0.06) to the full WL.

In all samples, irrigation was made with 5.25% sodium hypochlorite, saline, and 17% EDTA solution throughout the cleaning and shaping after each file and whenever there is a blockage in the root canal due to debris. Also, each (Ni-Ti) system was coated with glide file lubricant (EDTA 17% concentration, Vista, United States) throughout the whole procedure of cleaning and shaping.

Preparation of Roots for Sectioning

Sectioning of each block was carried out in horizontal plane perpendicular to the long axis of the tooth at 3, 6, and 9 mm from apex where the most apical 2 – 3 mm was discarded, and the remaining length was divided into three equal sections of 3 mm in length.⁶

The slices of 1 mm in thickness were taken from the middle of each section to represent mid-apical, mid-middle, and mid-coronal root canal thirds by using a water-cooled, low-speed IsoMet saw (Buehler Ltd., Lake Bluff, Illinois, United States), and three slices of 1 mm in thickness were accurately measured using a digital caliper (AR Instrumented, Germany) obtained from each specimen.¹²

Evaluation of Dentinal Cracks

The digital images were taken using a stereomicroscope with X40 magnification with the aid of an external high definition camera connected to the computer to enhance the resolution of the root section images. A total of 120 digital images (30 images/group) were examined for the presence of cracks¹², and root defects were classified as "no defect, complete cracks and other defects" according to Wilcox et al.¹³

Scanning Electron Microscope

Random samples from each group were obtained and prepared for SEM evaluation to confirm the results obtained from stereomicroscope as images of each section with cracks were taken at X50, X100, X350, and X500 magnifications as the baselines using SEM.¹⁴

Statistical Analysis

Statistical analysis was performed using SPSS (Chicago, Illinois, USA, version 18.0). KruskalWallis and Mann-Whitney tests were used for pairwise comparisons between all Ni-Ti groups at each third and all Ni-Ti groups regardless of third and between all the thirds regardless of Ni-Ti group.¹⁵ Whenever statistically significant difference was recorded among the levels, Mann-Whitney pairwise comparison test was then performed to compare between each two tested levels. All analyses were performed at a significance level of p value less than or equal to 0.05.

RESULTS

All the rotary file systems used in this study induce dentinal cracks. Group I showed no dentinal cracks (Fig.1). There are more dentinal cracks in group II followed by group IV as there was a statistically significant difference present ($p < 0.05$) (Fig.2 and Table 1).

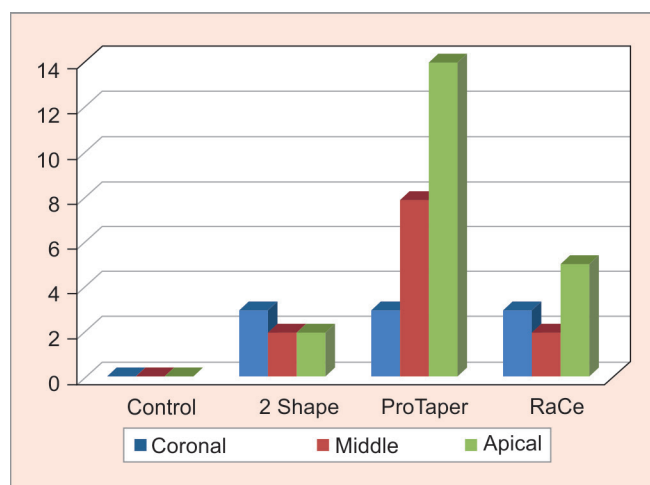
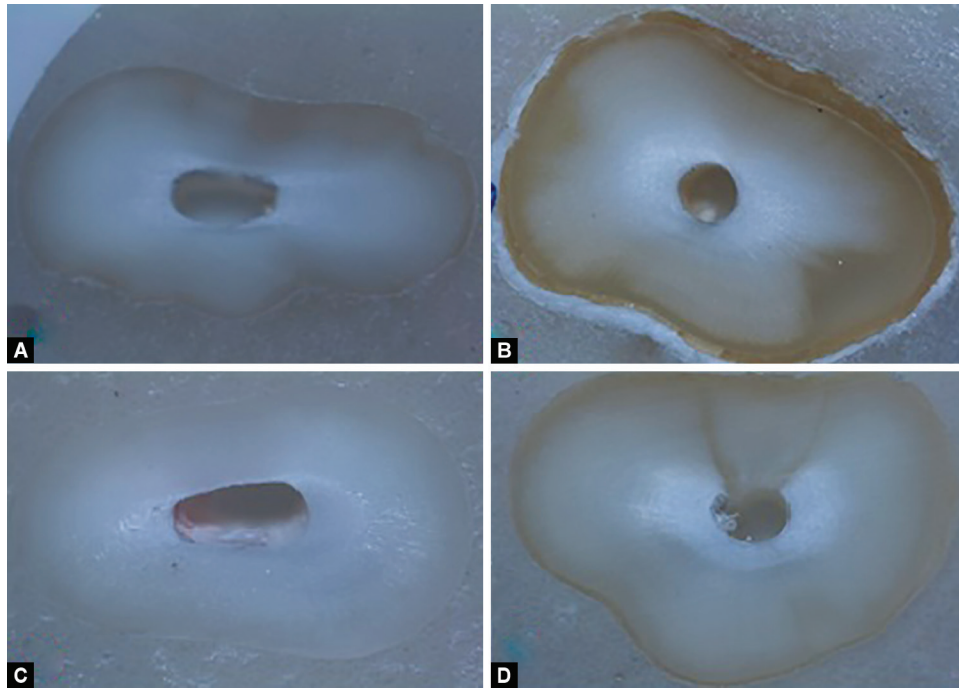


Fig. 1: Bar chart showing the number of specimens with cracks at different cross-sectional levels and their total percentages within each third



Figs 2A to D: Samples of the control group (A and B) showing the absence of cracks, samples instrumented with ProTaper Next system C and D with no cracks and presence of cracks

Table 1: Kruskal–Wallis nonparametric test for the different groups and their statistical value

Groups	N	Mean rank	Chi-square	df	p value
Group I (Control)	30	47.00	17.579	3	0.001
Group II (2 Shape)	30	59.83			
Group III (ProTaper)	30	74.43			
Group IV (RaCe)	30	60.73			

Table 2: Kruskal–Wallis nonparametric test for the different types of cracks and their statistical value in different cross sections

Position	N	Mean rank	Chi-square	df	p value
Coronal	40	58.28	1.247	2	0.536
Middle	40	59.10			
Apical	40	64.13			

Regarding groups, Kruskal-Wallis test was made to determine the different percentages of cracks in the three sections of each tooth, revealing that the apical third has the highest mean (64.13) and percentage of dentinal crack formation, and also a nonstatistical significance difference was found between the root sections ($p = 0.536$) as shown in Figure 3 and Table 2.

Comparison between different groups was performed, revealing no statistically significant differences between all groups except between groups I and III ($p = 0.888$) and groups II and III where $p = 0.063$ as shown in Table 3.

Table 3: Mann–Whitney U nonparametric test for two-group comparison and their statistical significance

	I vs II	I vs III	I vs IV	II vs III	II vs IV	III vs IV
Mann–Whitney U	332.000	443.000	345.000	345.000	255.000	345.000
Z	−2.092	−0.141	−2.791	−1.858	−4.004	−2.787
p value	0.036	0.888	0.005	0.063	0.000	0.005

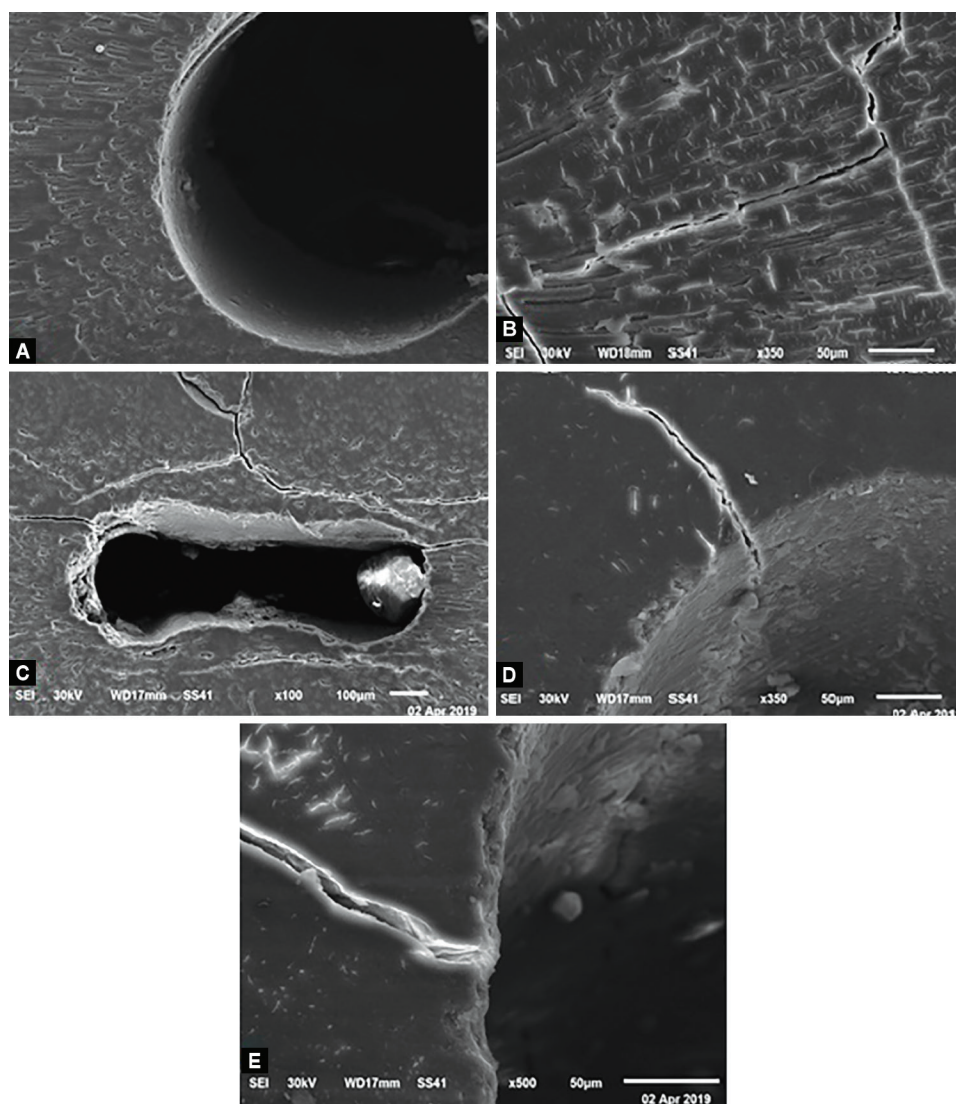
bold represents the highlight of the significance between groups (when found)

DISCUSSION

Proper and adequate biomechanical preparation is the most important step in endodontics as it greatly helps to achieve uniform hermetic three-dimensional obturation of the root canal system¹⁶ and prevent reinvasion of the bacteria as it may proliferate in crack lines and dentinal cracks that might be created during cleaning and shaping, furthermore establishing biofilms on the root surface and consequently failure of the whole procedure of endodontic treatment¹⁷ according to Singh et al.¹¹

After the instrumentation procedure, 35% or more of the canal surface as lateral canals, deep apical areas, and other irregularities remain intact and uninstrumented according to Peter et al.¹⁸ So, they provide an excellent environment for bacteria to colonize and cause the failure of root canal treatment.¹⁹

In Nazir et al's. study, statistical significant difference was found between cone - beam computed tomography (CBCT) and SEM when the total number of each type of defect was calculated.¹⁴ Craze lines were observed and detected only in SEM images but not in CBCT images due to the greater magnification power used ($\times 35$ and $\times 75 \mu\text{m}$) in SEM as consented by Cicek et al.²⁰ who found that craze lines (microcracks) were more obviously seen and detected using high magnification power ($\times 40 \mu\text{m}$), and Özer et al.²¹ found that CBCT scans showed failure in readings of fracture lines smaller than 0.2 mm.



Figs 3A to E: (A) SEM at x50 showing negative signs of dentinal cracks in apical section; (B) SEM at x350 showing dentinal cracks in apical section in 2 Shape group; (C) SEM at x100 showing multiple dentinal cracks around the root canal in the middle section in ProTaper Next group; (D) SEM at x350 showing dentinal cracks originating inside the root canal in the middle section in RaCe group; (E) SEM at x500 showing dentinal crack originating inside the root canal in the middle section and propagating toward the surface in RaCe group

The sectioning method has no effect on crack formation or propagation,²² which comes in agreement with several studies such as Bier et al.,⁴ Yoldz et al.,¹⁵ and Hin et al.,²³ who stated that some dentinal cracks might have been existed internal and may not be visible on the outer surface of the root. However, there were no cracks or fracture formation in the negative control group in the previous studies. On the contrary, Shemesh et al.²⁴ found that the sawing action somehow could result in dentinal microcracks.

In a study, direct visualization of the root canal system by using microscopic system would provide a better detection and understanding of the way of distribution of the dentinal cracks or any defects; so, stereomicroscope is used to visualize the defects and has many advantages as it is cost-effective, most common, fastest, high definition tool, and sensitive enough to identify the small area of cracks on the canal wall with the aid of $\times 30$ magnification loops for stereomicroscopic analysis.²⁵

Group I (Control): No dentinal cracks were found as seen in stereomicroscope, and SEM coronal enlargement and preflaring

are made using hand K-type stainless steel files #10 and #15 subsequently in what is called glide path creation, which is needed to prevent excessive instrument binding in the canal and subsequently decreasing any mishaps during the biomechanical preparation procedure.²⁶

Group II (2 Shape): Twenty-three percentage of dentinal cracks were observed in stereomicroscope and SEM as it comes in agreement with the study performed by Gündoğar et al. who stated that there is a direct relationship between the dentinal crack formation and the number of cycles to fracture for Ni-Ti file, and it was stated that Reciproc blue Ni-Ti files showed higher cyclic fatigue resistance than 2 Shape files. Moreover, the increase in the angle of curvature negatively affects the cyclic fatigue resistance and consequently more mishap as microcracks may even lead to excessive stresses on file and finally file fracture.²⁷

Group III (ProTaper Next): The current study revealed that ProTaper Next recorded higher dentinal crack formation compared to other groups as (83%) dentinal cracks were observed in stereomicroscope

and SEM, which comes in agreement with different studies regarding the Ni-Ti rotary file role in the dentinal crack formation as Capar et al.,²⁸ Karatas et al.,²⁹ and Cicek et al.²⁰ reported the incidence of dentinal cracks due to the use of ProTaper Next rotary Ni-Ti files in 28%, 33.3%, and 64.44% of samples, respectively. These results were agreed with results in a study conducted by Salem et al. who showed there is (21%) increase in dentinal cracks of ProTaper group and hand instrumentation as a control group.³⁰

In contrast to this finding, no significant difference was observed in the number of defects in dentin after preparation with four different rotary systems, HERO shaper, Revo-S, Twisted File, and Protaper Next in 60%, 25%, 40%, and 30% of samples, respectively, which was found by Yoldas et al.¹⁵ Also, Burklein et al.³¹ did not find any significant differences in the incidence of dentinal defects after root canal preparation by Ni-Ti rotary and reciprocal motion in any of the three sections between ProTaper (23.3%), Mtwo (18%) Reciproc (33.3%), and WavOne (30%). This controversy could be due to differences in group methodology as these studies compare both rotary and reciprocal motions and due to differences in apical preparation of sizes #30 and #40.

Similar study by Ashraf et al.¹⁷ has founded that ProTaper Next and HyFlex CM Ni-Ti rotary files have fewer tendencies to create dentinal cracks when compared with ProTaper Universal system that showed the highest percentage of dentinal cracks.

In another study by Staffooli et al., there were no significant differences in the centering ability induced by ProTaper Next and 2 Shape Ni-Ti file systems as they were subjected to the test in stimulated severely curved canals, and both systems showed some degree of transportation and microcrack formation, especially in the apical third that is considered a mishap.³²

Group IV (RaCe): Regarding group II, stereomicroscope and SEM revealed that 33% of dentinal cracks were observed, and this result comes in agreement with a study done by Garg et al. who showed that 10% of cracks were formed by RaCe files and they were less than K3 rotary files (16.7%). But this might be attributed to the difference in apical preparation in this study as it was performed till #25/4% not to #40/4%.³³

The current study revealed that the apical third is most susceptible for dentinal crack formation and propagation, and it comes in agreement with Nishad et al.³⁴ study results stating that ProTaper Next and ProTaper Universal have higher percentage of dentinal crack formation compared to ProTaper Gold.

This finding is in agreement with the results obtained by Adorno et al., as dentinal cracks were seen in 70%, 60% at the apical part at the fullWL, and 40%, 20% at 1 mL above the WL-1.^{35,36}

CONCLUSION

Within the limitation of the present *in vitro* study, the results suggested that

- Rotary preparation technique gives superior results than hand preparation technique, regarding time-consuming, canal shaping, and mechanical properties.
- ProTaper Next group showed a high percentage of dentinal cracks followed by RaCe, 2 Shape, and control groups regardless of the root canal cross-section.
- The highest percentage of dentinal crack incidence was in the apical third cross-section followed by middle and coronal thirds regardless of the Ni-Ti rotary system.

ORCID

Hisham M ELnazzar  <https://orcid.org/0000-0002-5756-1867>

REFERENCES

1. Garg E, Sarfi S, Bali D, et al. Comparative evaluation of dentinal defects induced by hand files, hyflex, protaper next and one shape during canal preparation: a stereomicroscopic study. *J Int Clin Dent Res Org* 2017;9(1):16. DOI: 10.4103/2231-0754.201735
2. Passarinho-Neto JG, Marchesan MA, Ferreira RB, et al. In vitro evaluation of endodontic debris removal as obtained by rotary instrumentation coupled with ultrasonic irrigation. *Aust Endod J* 2006;32(3):123-128. DOI: 10.1111/j.1747-4477.2006.00035.x.
3. Mishra N, Qureshi R, Agarwal M, et al. Challenges and current concepts in the preparation of root canal systems in radix entomolaris case reports. *J Dent Med Sci* 2016;15(2):77-81. DOI: 10.9790/0853-15267781.
4. Bier CAS, Shemesh H, Tanomaru-Filho M, et al. The ability of different nickel-titanium rotary instruments to induce dentinal damage during canal preparation. *J Endod* 2009;35(2):236-238. DOI: 10.1016/j.joen.2008.10.021.
5. Kansal R, Rajput A, Talwar S, et al. Assessment of dentinal damage during canal preparation using reciprocating and rotary files. *J Endod* 2014;40(9):1443-1446. DOI: 10.1016/j.joen.2014.02.015.
6. Harandi A, Mirzaeerasad S, Mehrabani M, et al. Incidence of dentinal crack after root canal preparation by ProTaper Universal, Neolix and SafeSider systems. *Iran Endod J* 2017;12(4):432. DOI: 10.22037/iej.v12i4.17597.
7. Chauhan R, Tikku A, Chandra A. Detection of residual obturation material after root canal retreatment with three different techniques using a dental operating microscope and a stereomicroscope: an in vitro comparative evaluation. *J Conserv Dent* 2012;15(3):218. DOI: 10.4103/0972-0707.97940.
8. Jain A, Bhadoria K, Choudhary B, et al. Comparison of dentinal defects induced by hand files multiple and single rotary files: a stereomicroscopic study. *World Dent J* 2017;8(1):45-48. DOI: 10.5005/jp-journals-10015-1409.
9. Ferrara G, Taschieri S, Corbella S, et al. Comparative evaluation of the shaping ability of two different nickel-titanium rotary files in curved root canals of extracted human molar teeth. *J Investig Clin Dent* 2017;8(1):15-8. DOI: 10.1111/jicd.12187.
10. Das S, Pradhan PK, Lata S, et al. Comparative evaluation of dentinal crack formation after root canal preparation using ProTaper Next, OneShape, and Hyflex EDM. *J Conserv Dent* 2018;21(2):153-6. DOI: 10.4103/JCD.JCD_219_17.
11. Singh TK, Mathur R, Passi D, et al. To study the crack initiation on the apical root surface following different root canal preparation techniques and instruments: an in vitro study. *Ann Med Health Sci Res* 2018;8(3):55-59.
12. Liu R, Hou BX, Wesselink PR, et al. The incidence of root microcracks caused by 3 different single-file systems versus the ProTaper system. *J Endod* 2013;39(8):1054-1056. DOI: 10.1016/j.joen.2013.04.013.
13. Wilcox LR, Roskelley C, Sutton T. The relationship of root canal enlargement to finger-spreader induced vertical root fracture. *J Endod* 1997;23(8):533-534. DOI: 10.1016/S0099-2399(97)80316-0.
14. Nazir SM, Abdallah AM, Mokhless NA. Detection of crack formation following coronal flaring with three different instruments using two evaluation methods-in-vitro study. *Alexandria Dent J* 2017;42(2):135-140. DOI: 10.21608/ADJALEXU.2017.57916.
15. Yoldas O, Yilmaz S, Atakan G, et al. Dentinal microcrack formation during root canal preparations by different NiTi rotary instruments and the self-adjusting file. *J Endod* 2012;38(2):232-235. DOI: 10.1016/j.joen.2011.10.011.
16. Cordeiro MM, Rocha MJ. The effects of periradicular inflammation and infection on a primary tooth and permanent successor. *J Clin Pediatr* 2005;29(3):193-200. DOI: 10.17796/jcpd.29.3.5238p10v21r2j162.
17. Ashraf F, Shankarappa P, Misra A, et al. A stereomicroscopic evaluation of dentinal cracks at different instrumentation lengths by using different rotary files (ProTaper Universal, ProTaper Next, and

- HyFlex CM): an ex vivo study. *Sci (Cairo) J* 2016;2016:837–865. DOI: 10.1155/2016/8379865.
18. Peters O. Current challenges and concepts in the preparation of root canal systems: a review. *J Endod* 2004;30(8):559–67. DOI: 10.1097/01.don.0000129039.59003.9d.
 19. Jiang LM, Lak B, Eijssvogels LM, et al. Comparison of the cleaning efficacy of different final irrigation techniques. *J Endod* 2012;38(6):838–841. DOI: 10.1016/j.joen.2012.03.002.
 20. Çiçek E, Koçak MM, Sağlam BC, et al. Evaluation of microcrack formation in root canals after instrumentation with different NiTi rotary file systems: a scanning electron microscopy study. *Scanning* 2015;37(1):49–53. DOI: 10.1002/sca.21178.
 21. Özer 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(7):1245–1249. DOI: 10.1016/j.joen.2010.03.021.
 22. Kinici D, Çolak Topçu M, Karataş E. Comparison of the effect of different glide path Ni-Ti rotary systems on the formation of dentinal crack on curved root canals. *Turk Endod J* 2017;2(1):1–4. DOI: 10.14744/TEJ.2016.03522.
 23. Hin ES, Wu M-K, Wesselink PR, et al. Effects of self-adjusting file, Mtwo, and ProTaper on the root canal wall. *J Endod* 2013;39(2):262–264. DOI: 10.1016/j.joen.2012.10.020.
 24. Shemesh H, Wesselink PR, Wu MK. Incidence of dentinal defects after root canal filling procedures. *J Endod* 2010;43(11):995–1000. DOI: 10.1111/j.1365-2591.2010.01740.x.
 25. Strani F, Profico A, Manzi G, et al. MicroWear: a new R package for dental microwear analysis. *Ecol Evol J* 2018;8(14):7022–7030. DOI: 10.1002/ece3.4222.
 26. Patino P, Biedma B, Liebana C, et al. The influence of a manual glide path on the separation rate of NiTi rotary instruments. *J Endod* 2005;31(2):114–116. DOI: 10.1097/01.don.0000136209.28647.13.
 27. Gündoğar M, Özyürek T. Cyclic fatigue resistance of OneShape, HyFlex EDM, WaveOne gold, and Reciproc blue nickel-titanium instruments. *J Endod* 2017;43(7):1192–1196. DOI: 10.1016/j.joen.2017.03.009.
 28. Capar ID, Arslan H, Akcay M, et al. Effects of ProTaper Universal, ProTaper Next, and HyFlex instruments on crack formation in dentin. *J Endod* 2014;40(9):1482–1484. DOI: 10.1016/j.joen.2014.02.026.
 29. Karataş E, Gündüz HA, Kırıcı DÖ, et al. Dentinal crack formation during root canal preparations by the twisted file adaptive, ProTaper Next, ProTaper Universal, and WaveOne instruments. *J Endod* 2015;41(2):261–264. DOI: 10.1016/j.joen.2014.10.019.
 30. Milani AS, Froughreyhani M, Rahimi S, et al. The effect of root canal preparation on the development of dentin cracks. *Iran Endod J* 2012;7(4):177.
 31. Bürklein S, Tsotsis P, Schäfer E. Incidence of dentinal defects after root canal preparation: reciprocating versus rotary instrumentation. *J Endod* 2013;39(4):501–504. DOI: 10.1016/j.joen.2012.11.045.
 32. Staffoli S, Özyürek T, Hadad A, et al. Comparison of shaping ability of ProTaper Next and 2Shape nickel–titanium files in simulated severe curved canals. *G Ital Endod* 2018;32(2):52–56. DOI: 10.1016/j.gien.2018.05.002.
 33. Garg S, Mahajan P, Thaman D, et al. Comparison of dentinal damage induced by different nickel-titanium rotary instruments during canal preparation: an in vitro study. *J Conserv Dent* 2015;18(4):302–305. DOI: 10.4103/0972-0707.159730.
 34. Nishad SV, Shivamurthy G. 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;9(5):34. DOI: 10.4103/ccd.ccd_830_17.
 35. Adorno CG, Yoshioka T, Suda H. Crack initiation on the apical root surface caused by three different nickel-titanium rotary files at different working lengths. *J Endod* 2011;37(4):522–525. DOI: 10.1016/j.joen.2010.12.002.
 36. Adorno CG, Yoshioka T, Suda H. The effect of root preparation technique and instrumentation length on the development of apical root cracks. *J Endod* 2009;35(3):389–392. DOI: 10.1016/j.joen.2008.12.008.