Available online at www.medicinescience.org

ORIGINAL ARTICLE

Medicine Science International Medical Journal

Medicine Science 2025;14(2):411-6

Assessment of apically extruded debris and preparation times with different file systems in primary molar teeth

Murside Seda Dulger, Huseyin Simsek

Ordu University, Faculty of Dentistry, Department of Pedodontics, Ordu, Türkiye

Received 05 February 2025; Accepted 25 April 2025
Available online 31 May 2025 with doi: 10.5455/medscience.2025.01.018

Content of this journal is licensed under a Creative Commons Attribution-NonCommercial-NonDerivatives 4.0 International License.

Abstract

The aim of this study was designed to compare the quantity of extrusion debris from apical foramen and the instrumentation time of four different file systems in primary teeth. Eighty extracted primary mandibular molar teeth were randomly divided into four groups considering the four different file systems (n=20). The samples from each group (Group 1: Hand Files, Group 2: WaveOne Gold (WOG), Group 3: ProTaper Next (PTN), Group 4: TP Adaptive (TFA)) were instrumented according to the instructions from the manufacturers. The extrusion debris from apical foramen during instrumentation was gathered in pre-weighed Eppendorf tubes, which were subsequently incubated at 70°C for five days. The dried extruded debris weight for each group was determined by calculating the difference between the final weight of the tubes and their initial weight before instrumentation from the weight after instrumentation. Data were assessed statistically using the Mann-Whitney U and the Kruskal Wallis analysis test. In the evaluation of instrumentation time, data were analyzed using one-way analysis of variance (ANOVA) and the Tukey's post-hoc test. There was a significant difference in the quantity of extrusion debris from apical foramen among the studied groups ($p<0.05$). The quantity of extruded debris was showed highest in the PTN, and the lowest in the TFA and Hand File groups ($p<0.05$). Accordingly, the longest instrumentation time was observed with the TFA file system ($p<0.05$). All instruments resulted in extrusion debris from apical foramen in the primary molar teeth. However, the hand files and TFA extruded less extruded debris compared to other systems.

Keywords: Apical extrusion, hand files, endodontic file systems

Introduction

Root canal applications is recommended for primary molar tooth exhibiting pulp necrosis or irreversible pulpitis [1]. A fundamental objective of root canal application is to achieve complete debridement of the tooth's root canal through chemomechanical preparation [2]. Studies indicates that all preparation and instrument tecniques for root canals result in the extrusion of irrigants, debris, and microorganisms from the apical foramen [3]. Walia et al. [4] designed hand instruments made of NiTi instruments and offered them to clinical use. A few studies showed that, when compared to the stainless-steel files, the files made of NiTi alloy had higher fracture resistance and lower elastic module. For this reason, the NiTi instruments are preferred more in the root canal shaping, especially for the narrow and curved canals [5,6].

It is recommended to perform the root canal treatments of the primary molar tooth with NiTi files since they have a good flexible structure [7]. The conic form obtained by the use of NiTi files makes it easier to fill the root canals. Besides, this method makes placing the paste easier and minimizes the risk of the excessive filling [8]. The ProTaper Next (PTN) rotary file system, which is generated with the improvement of ProTaper Universal (PTU) both in terms of design and metallurgy, is a new generation file system. The newly developed M-Wire alloy provides greater flexibility and superior cyclic fatigue resistance than standard NiTi alloys [9]. The most important design difference of the files used in the PTU is having an off-centered bilateral symmetric rectangular cross-section [10,11].

Recently developed by Dentsply Maillefer Company over the previously manufactured WaveOne, the WaveOne Gold (WOG)

CITATION
Dulger MS, Simsek H. Assessment of apically extruded debris and preparation times with different file systems in primary molar teeth. Med Science. 2025;14(2):411-6.

Corresponding Author: Huseyin Simsek, Ordu University, Faculty of Dentistry, Department of Pedodontics, Ordu, Türkiye
Email: dr.huseyinsimsek@gmail.com

DOI: 10.5455/medscience.2025.01.018

is a single-file reciprocating system as its predecessor. Unlike WaveOne, which incorporates M-Wire; WOG producted a recently developed alloy whose tradename is Gold Wire [11]. WOG features a parallelogram-shaped cross-section with dual cutting edges at an 85-degree angle, which contact the root canal walls alternately. The asymmetrical cross-section decreases the file's contact with the canal wall during operation, minimizing the risk of binding and threading commonly seen in continuous movement systems [11].

Twisted File Adaptive System (TFA) (SybronEndo, Orange County, CA, USA) is a combination of reciprocal and continuous rotary motion. If there is no resistance, the file works with a continuous rotation motion. This gives a better cutting efficacy and debris extrusion. On the other hand, when the file maintains close contact with the dentin under an applied load, it operates using a reciprocating motion. Thus, it is aimed to eliminate the instrumental failures during canal preparations [12]. According to the manufacturer, the adaptive behavior and flexible files of the system reduce the load on the file, the system improves torsional resistance [10,13].

Evaluating the instrumentation time of various file systems or shaping techniques aims to provide insights into their efficiency and clinical practicality [14]. Recent studies have revealed that utilizing motorized NiTi file systems leads to fewer iatrogenic errors, better shaping in root canals, and reduced instrumentation time [5,15].

The mechanisms and factors contributing to apically extruded debris in primary molar tooth remain inadequately understood. This study is important for pediatric endodontics, as excessive apical debris extrusion can cause postoperative pain and inflammation, while longer preparation times may affect patient cooperation. Identifying an efficient file system can enhance treatment safety and comfort for young patients. The hypothesis of this study is that different file systems will produce varying amounts of apically extruded debris and preparation times in primary molar teeth. Identifying an optimal system could improve treatment efficiency and patient comfort in pediatric endodontics.The purpose of this study was to evaluate amount of extrusion debris from apical foramen and the instrumentation time using hand files, WOG, TFA, and PTN in the primary molar root canals, considering their design and motion mechanisms.

Material and Methods

Sample Size Calculation

The ethical approval of this study was obtained from the Clinical Research Ethical Committee of Ordu University (ID number: 2019/87) (Approval date: 2019; Number: 87). The sample size estimation was carried out via G Power, version 3.1 (Dusseldorf, Germany), α=0.05 and %91 Power, as well as the study, carried out by Burklein et al. [16]. After the Power analysis, it was determined that, in total, 60 recently extracted secondary molar teeth would suffice for the study. A total of 80 teeth were used to enhance the reliability of the study.

Sample Preparation

This is an in vitro study applied on 80 mandibular secondary primary molar teeth which were extracted due to decay or orthodontic purposes. The mesiobuccal roots of the teeth which are single , narrow, and round-shaped canal were preferred. The selected teeth were maintained in distilled water and radiographed buccolingually, mesiodistally and at 60º angle. The samples were collected based on the following inclusion criteri: root curvature between 10º-20º, no prior root canal treatment, having no internal/external resorption and radiographical confirmation of having single canal without any aberrant canal in the mesial root.

In order to locate them on the holes created at the caps of Eppendorf tubes, with the respective part of the crown, the distal roots of each tooth, were separated at the furcation area with a diamond fissure burs (Kavo, Biberach Riss, Germany) with water and discarded. All teeth were dried and inserted into tubes. The instrumentation size of each canal was calculated via a 10 K hand file (Mani Inc., Tochigi, Japan). A 1 mm shorter length than the root apex was selected as the working length for each tooth. The specimens were distributed randomly among 4 groups, each group having 20 teeth (n=20).

Debris Collection

Myers and Montgomery [17] technique was used to measure the quantity of apically extruded debris. Holes were created on the caps of Eppendorf tubes with diamond burs to insert the teeth. It was made sure that the tubes were clean, dry and empty. Before the instrumentation process, a microbalance with a sensitivity of 10^{-4} g was used to weigh the Eppendorf tubes (Radwag, Poland). Each tube was weighed three times, and the avarage value of these measurements was recorded.

The roots were carefully inserted into the opened holes on the caps of the Eppendorf tubes. To prevent pressure build-up during the procedure, a 27-gauge needle (Hayat Şırınga, İstanbul, Türkiye) was placed adjacent to the cover, serving as a drainage cannula to balance external and internal air pressure. Tubes were placed in opaque brown vials to obscure the visibility of the extruded debris from the examiner, ensuring blinding during the evaluation process.

Preparation with Hand Files

The root canals were prepared with a standardized preparation technique by using size 20, 25 and 30 K hand files (Mani Inc., Tochigi, Japan). The K files were used by rotating 90º, 180º, 270º and 360º respectively. After each rotation, the file was withdrawn, and any residue adhering to it was cleaned. All of the instruments were used until they moved freely in the canal, after each file the bigger size was performed.

Preparation with PTN

PTN were used at a 200 gcm torque and 300 rpm. After using the 15K hand file to determine the working length, files were sequentially applied in the order of X1 (20.04), X2 (25.06), and X3 (30.07), using a brushing motion during the procedure.

DOI: 10.5455/medscience.2025.01.018

Preparation with WOG

In respect to the WOG setting, which was recorded to its memory, the endodontic motor (X-Smart Plus) used in this group rotates 150º anticlockwise and 30º clockwise. The working length was controlled with a size 15 K hand file. In accordance with the instructions of the manufacturer, the shaping was made in the sequence of WaveOne Gold (20.07), (25.07) and (35.06) files. The file was applied a brushing motion.

Preparation with TFA

TFA were used with the "TF Adaptive" program with their own motor (Elements Motor, Sybronendo) in the files of SM1 (20.04), SM2 (25.06) and SM3 (35.04).

In each group, the teeth were cleaned with distilled water (Distilled Water, Naturel Medical, Istanbul, Turkey). During the irrigation, a 29-gauge irrigation needle was used, and the needle was localized 1 mm shorter than the working length. The teeth were irrigated before the preparation, during each instrument change, and after the preparation to remove the debris from the root surface. Each canal was irrigated with 5 ml of distilled water. Each instrument was utilized for the preparation of only three canals, with all procedures conducted by a single operator to ensure consistency.

The Calculation of Apically Extruded Debris

After canal preparation, the needles and teeth were withdrawn from the Eppendorf tubes, and removed from the vials. The tubes were subsequently placed in an incubator with their caps removed and stored at 70ºC for five days, allowing the distilled water to evaporate, leaving only the dry debris for weighing. Once the samples were ready, the tubes were weighed three times consecutively using the same precision balance, and the average value for each tube was recorded. The quantity of apically extruded dry debris was determined by calculating the difference between the pre-procedure and post-procedure weights of the tubes.

Evaluation of the Instrumentation Time

A chronometer was used to record the preparation time of each tooth. The evaluation of instrumentation time included the time required to change files and clean debris from the file surface.

Statistical Analysis

Statistical analyses were conducted using SPSS software (version 18.0; SPSS Inc., Chicago, IL, USA). The Kruskal-Wallis test was employed to evaluate differences in the mean values of apically extruded debris among the four file systems. Pairwise comparisons were subsequently conducted using the Mann-Whitney U test. For the analysis of instrumentation time, a one-way analysis of variance (ANOVA) was applied, followed by Tukey's Post Hoc test for pairwise comparisons. Statistical significance was determined at a level of 0.05.

Results

Results of Apically Extruded Debris

Mean scores and standard deviations for all groups are shown in Table 1. PTN extruded more debris compared to TFA and Hand File groups ($p<0.05$). No statistically significant difference was observed between the hand file groups ($p>0.05$). Besides, no significant difference was found between ProTaper Next and WaveOne Gold groups ($p>0.05$). The difference among the rest of the groups was statistically significant.

Table 1. Weight of the apically extruded debris after instrumentation of root canals with the experimental groups (g) and Post Hoc tests

Groups	N	Minimum	Maximum	Mean	Standard deviation	p	Post Hoc test					
HF	20	.000240	.0025000	.0010	.00057	**.001***	p value					
PTN	20	.00000	.028660	.0044	.00755		**TFA-PTN**	**TFA-HF**	**TFA-WOG**	**PTN-HF**	**PTN-WOG**	**HF-WOG**
WOG	20	.000540	.004430	.0019	.00103		**.005***	.735	**.008***	**.003***	.465	**.006***
TFA	20	.000100	.002800	.0010	.00081							

p<0.05, HF: Hand File, PTN: ProTaper Next, WOG: WaveOne Gold, TFA: Twisted File Adaptive

Results of Instrumentation Time

The mean values of the instrumentation time of the groups and the differences among these values are listed in Table 2. TFA had the longest instrumentation time ($p<0.05$). The hand file system demonstrated the shortest instrumentation time among the four groups. However, compared to the other three groups; however, the observed was not statistically significant ($p>0.05$).

Table 2. Results of instrumentation time (sc)

Groups	N	Minimum	Maximum	Mean	Standard deviation	p
Hand File	20	253.00	389.00	293.4500[a]	29.65854	**.000***
ProTaper Next	20	241.00	407.00	305.8000[a]	44.44464	
WaveOne Gold	20	283.00	341.00	314.7500[a]	15.13057	
TF Adaptive	20	251.00	551.00	383.4500[b]	60.55313	

p<0.05, statistically significant difference; the same superscript letters indicate statistically no significant values

DOI: 10.5455/medscience.2025.01.018

Discussion

The preparation and irrigation of canals can cause inflammatory reactions by the extruded components, such as; microorganisms, necrotic pulp tissue and dentin chips. Therefore, several studies have been conducted to show that files used in root canal enstrumentation including NiTi rotary and hand file systems, cause apically extruded debris in permanent teeth [10,18]. This condition is more important in deciduous dentition when compared to permanent dentition. Root canal disinfectants can negatively affect underlying stem cells, leading to developmental changes in the dental germ. These changes may include enamel or dentin hypoplasia, morphological deformities in the dental crown, or even a complete halt in root development [19].

In in vitro studies, several methods are used to calculate the apically extruded debris. The our study employed the approach as modified by Tinaz et al. [20]. The Eppendorf tubes were placed into nontransparent brown vials. This measure ensured that the examiner remained blinded to the quantity of extrusion debris from apical, as well as any waste material from adhering to the Eppendorf tubes. Distilled water was choosen as the irrigant to prevent any potential crystallization of NaOCl, which could otherwise compromise the accuracy of extruded debris measurements. To standardize the samples, mesiobuccal roots of the mandibular molar teeth were preferred for the study and the patency of the apical foramen was determined with a size 10 K-file.

Because of the limited number of studies conducted on the application of NiTi instruments on primary molar teeth, the results of this study were compared with not only the studies conducted on primary teeth, but also permanent teeth. In these studies designs, manufacturing methods and kinematics of the file systems were compared. Our study compares different file systems such as hand file, ProTaper Next, WaveOne Gold and TF Adaptive, with regard to their extruded debris from apical foramen during root canal enstrumentation of primary molar tooth. Üstün et al. [21] analyzed the quantitiy of extruded debris with WaveOne, PTN, and TFA in single canal teeth and showed that PTN extruded higher debris than all other groups, a result that aligns with the findings of the current study. Singh et al. [22] compared ProTaper, M-two and WaveOne file systems as regards to their extrusion of apical debris. Even though they observed slightly more apical extrusion of irrigants and debris during the instrumentation of the WaveOne file system, no difference was found among the groups. De-Deus et al. [23] compared the quantity of debris extrusion during canal enstrumentation with Reciproc, WaveOne single-file system and hand files, and multiple-file ProTaper system and determined that the ProTaper system was found to extrude more debris compared to the systems using reciprocal motion. It was thought that, in comparison to rotary systems, the reciprocal systems had better control over apically extruded debris [24]. Our study determined that the WOG system extruded less quantity of debris in comparison with other systems.

Çapar et al. [10] reported the quantity of debris extrusion of apical using the ProTaper Next, ProTaper Universal, TFA, and Hyflex file systems. They found that PTN and TFA systems resulted in significantly lower amounts of apically extruded debris than the other systems. The findings of TFA matched with the findings of our study; however, in our study, we determined that ProTaper Next extruded the maximum amount of apical debris. The apical diameter of the sample changes, the ratio of the rotary and reciprocal movement has also changed in the Twisted File Adaptive system. This difference may be attributed to PTN's more aggressive cutting design, greater taper, and continuous rotary motion, which could push more debris toward the apex. In contrast, the adaptive motion of TFA may allow better control over debris extrusion, especially in narrow and curved root canals of primary molars. Variations in tooth anatomy, operator technique, and sample selection may also contribute to these differing results.

The features of the files such as their helicoidal angles, rake, and cross-section, the distance between, alloy, tip design, taper, flexibility, flutes and size may affect apically extruded debris [25]. The WOG file has a cross-section of parallelogram-shaped, and during instrumentation, only one of its cutting edges engages with the canal wall. The increased clearance around the instrument aids in the removal of debris. Additionally, the active portion of the file features a consistent helical angle of 24º [26]. In this study, the WOG group extruded less debris compared to the PTN. A potential reason for this outcome is that the additional space around the WOG instrument may allow for debris accumulation and its subsequent removal from the coronal area. In line with the current study, Arya et al. [27] determined that the hand file group extruded less amount of apical debris in their study. This decreases the engagement between the dentin and file [28]. This could result in less prepared dentin walls and more debris amount. Lumley et al. [29] argued that files with smaller tapers gave better results in canal preparation. Thus, it can be said that the smaller tapers of the hand files may cause them to extrude less debris. Previous studies have showed that the amount of extrusion apical debris may be influenced by inherent physical factors related to canal anatomy, as well as mechanical reasons, including the chosen instrumentation techniques. However, present methods are not efficient to eliminate the debris extrusion [18,23]. In the current study, apical debris extrusion were reported for every root canal shaping method. However, the TFA used with endodontic motor and hand files caused less debris extrusion from the apical foramen. As it operated on both reciprocal and rotary movements, the TFA increased the advantage of reciprocal movement and minimized the disadvantages of the rotational movement [7]. In this study, the ProTaper Next system was found to extrude the highest amount of debris from the apical foramen. It could be due to its aggressive design [30]. The results of the previous studies that reciprocation files are related with reduced apically extruded debris in comparison to

DOI: 10.5455/medscience.2025.01.018

rotary systems correlate with the results of this study [3,31]. Nonetheless, no difference was determined between these two file systems in our study.

In several studies, as current study, while amount of extruded debris from apical foramen related with various file systems, instrumentation time of these systems were also compared. Katge et al. [8,10] evaluated the preparation time of hand file, ProTaper and WaveOne on maxillary and mandibular primary molar teeth and showed that The WaveOne system demonstrated a significantly shorter instrumentation time in comparison to the other systems. Uzun et al. [32] demonstrated that single-file systems enabled more rapid canal preparation compared to multiple-file systems. Conversely, Ehsani et al. [33] showed no differences in the instrumentation times of the OneShape, WaveOne, and Reciproc file systems. In our study, however, the TFA demonstrated the longest preparation time, which was statistically significant. The reason for the longer instrumentation time of the TFA Adaptive system might be originated from the changes in its movement kinematics when it encounters pressure or resistance in narrow root canals. When the literature was reviewed, it was observed that studies showed Reciproc instruments having faster preparation time than other systems, [16,32] as well as studies showed vice versa [34]. It can be argued that the difference among these studies may arise from different working protocols and the experience of the operator. The present study has several limitations. First, as an in vitro investigation, it may not fully replicate clinical conditions. Although efforts were made to standardize the sample selection, anatomical variations in primary molar teeth may have influenced the outcomes. Additionally, only the mesiobuccal canals of lower primary molars were used, which may limit the generalizability of the findings to other canal types or tooth groups. The use of a single irrigant (distilled water) and a fixed irrigation protocol also does not reflect the variability seen in clinical practice.

Conclusion

Considering the limitations of the our study, all enstrumentation systems evaluated were found to cause extrusion of apically exruded debris. When compared to others, TFA files had the minimum amount of debris extrusion. The clinical relevance of this study lies in its direct implications for pediatric endodontic practice. Primary teeth have unique anatomical and physiological characteristics, and excessive apical extrusion during root canal treatment can lead to postoperative pain, periapical inflammation, and potential damage to the developing permanent tooth germ. By comparing the amount of apically extruded debris and the instrumentation times of different file systems, this study provides valuable insights into selecting safer and more efficient instrumentation techniques for young patients. Minimizing debris extrusion and reducing preparation time are crucial factors in enhancing patient comfort, improving cooperation during treatment, and ultimately ensuring better treatment outcomes in pediatric dentistry.

Conflict of Interests
The authors declare that there is no conflict of interest in the study.

Financial Disclosure
The authors declare that they have received no financial support for the study.

Ethical Approval
This study was approved by Clinical Research Ethical Committee of Ordu University (ID number: 2019/87) (Approval date: 2019; Number: 87).

References

1. Aboujaoude S, Noueiri B, Berbari R, et al. Evaluation of a modified Pulpotec endodontic approach on necrotic primary molars: a one-year follow-up. Eur J Paediatr Dent. 2015;16:111-4.
2. Barbizam JVB, Fariniuk LF, Marchesan MA, et al. Effectiveness of manual and rotary instrumentation techniques for cleaning flattened root canals. J Endod. 2002;28:365-6.
3. Koçak S, Koçak MM, Sağlam BC, et al. Apical extrusion of debris using self-adjusting file, reciprocating single-file, and 2 rotary instrumentation systems. J Endod. 2013;39:1278-80.
4. Walia H, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of Nitinol root canal files. J Endod. 1988;14:346-51.
5. Bahia MGA, Buono VTL. Decrease in the fatigue resistance of nickel-titanium rotary instruments after clinical use in curved root canals. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2005;100:249-55.
6. Thompson S. An overview of nickel–titanium alloys used in dentistry. Int Endod J. 2000;33:297-310.
7. Gungor OE, Kustarci A. Evaluation of apically extruded debris using two NiTi systems associated with two irrigation techniques in primary teeth. J Clin Pediatr Dent. 2016;40:490-5.
8. Silva LA, Nelson-Filho P, Leonardo MR, Tanomaru JM. Comparison of rotary and manual instrumentation techniques on cleaning capacity and instrumentation time in deciduous molars. J Dent Child. 2004;71:45-7.
9. Johnson E, Lloyd A, Kuttler S, Namerow K. Comparison between a novel nickel-titanium alloy and 508 nitinol on the cyclic fatigue life of ProFile 25/.04 rotary instruments. J Endod. 2008;34:1406-9.
10. Capar ID, Arslan H, Akcay M, Ertas H. An in vitro comparison of apically extruded debris and instrumentation times with ProTaper Universal, ProTaper Next, Twisted File Adaptive, and HyFlex instruments. J Endod. 2014;40:1638-41.
11. Ruddle CJ, Machtou P, West JD. The shaping movement 5th generation technology. Dent Today. 2013;34:94-9.
12. Gambarini G, Gergi R, Naaman A, et al. Cyclic fatigue analysis of twisted file rotary NiTi instruments used in reciprocating motion. Int Endod J. 2012;45:802-6.
13. Gergi R, Arbab-Chirani R, Osta N, Naaman A. Micro–computed tomographic evaluation of canal transportation instrumented by different kinematics rotary nickel-titanium instruments. J Endod. 2014;40:1223-7.
14. Hülsmann M, Peters OA, Dummer PM. Mechanical preparation of root canals: shaping goals, techniques and means. Endod Topics. 2005;10:30-76.
15. Guelzow A, Stamm O, Martus P, Kielbassa A. Comparative study of six rotary nickel–titanium systems and hand instrumentation for root canal preparation. Int Endod J. 2005;38:743-52.
16. Bürklein S, Benten S, Schäfer E. Quantitative evaluation of apically extruded debris with different single-file systems: Reciproc, F360 and OneShape versus Mtwo. Int Endod J. 2014;47:405-9.

DOI: 10.5455/medscience.2025.01.018

17. Myers GL, Montgomery S. A comparison of weights of debris extruded apically by conventional filing and Canal Master techniques. J Endod. 1991;17:275-9.

18. Xavier F, Nevares G, Romeiro M, et al. Apical extrusion of debris from root canals using reciprocating files associated with two irrigation systems. Int Endod J. 2015;48:661-5.

19. Cordeiro MM, Rocha MJ. The effects of periradicular inflamation and infection on a primary tooth and permanent successor. J Clin Pediatr Dent. 2005;29:193-200.

20. Tinaz AC, Alacam T, Uzun O, et al. The effect of disruption of apical constriction on periapical extrusion. J Endod. 2005;31:533-5.

21. Üstün Y, Çanakçi B, Dinçer A, et al. Evaluation of apically extruded debris associated with several Ni–Ti systems. Int Endod J. 2015;48:701-4.

22. Singh A, Arunagiri D, Pushpa S, et al. Apical extrusion of debris and irrigants using ProTaper hand, M-two rotary and WaveOne single file reciprocating system: an ex vivo study. J Conserv Dent. 2015;18:405-8.

23. De-Deus G, Neves A, Silva EJ, et al. Apically extruded dentin debris by reciprocating single-file and multi-file rotary system. Clin Oral Investig. 2015;19:357-61.

24. McKendry DJ. Comparison of balanced forces, endosonic, and step-back filing instrumentation techniques: quantification of extruded apical debris. J Endod. 1990;16:24-7.

25. Caviedes-Bucheli J, Moreno J, Carreno C, et al. The effect of single-file reciprocating systems on S ubstance P and C alcitonin gene-related peptide expression in human periodontal ligament. Int Endod J. 2013;46:419-26.

26. Webber J. Shaping canals with confidence: WaveOne GOLD single-file reciprocating system. International Dentistry – African Edition. Reprinted with permission by Roots 2015;1:34-40.

27. Arya A, Bali D, Grewal MS. Histological analysis of cleaning efficacy of hand and rotary instruments in the apical third of the root canal: a comparative study. J Conserv Dent. 2011;14:237-40.

28. Blum J, Machtou P, Ruddle C, Micallef J. Analysis of mechanical preparations in extracted teeth using ProTaper rotary instruments: value of the safety quotient. J Endod. 2003;29:567-75.

29. Lumley P. Cleaning efficacy of two apical preparation regimens following shaping with hand files of greater taper. Int Endod J. 2000;33:262-5.

30. Loizides AL, Kakavetsos VD, Tzanetakis GN, et al. A comparative study of the effects of two nickel–titanium preparation techniques on root canal geometry assessed by microcomputed tomography. J Endod. 2007;33:1455-9.

31. Lu Y, Chen M, Qiao F, Wu L. Comparison of apical and coronal extrusions using reciprocating and rotary instrumentation systems. BMC Oral Health. 2015;15:92.

32. Uzun I, Güler B, Özyürek T, Tunc T. Apical extrusion of debris using reciprocating files and rotary instrumentation systems. Niger J Clin Pract. 2016;19:71-5.

33. Ehsani M, Farhang R, Harandi A, et al. Comparison of apical extrusion of debris by using single-file, full-sequence rotary and reciprocating systems. J Dent (Tehran, Iran). 2016;13:394-9.

34. Alves FR, Marceliano-Alves MF, Sousa JCN, et al. Removal of root canal fillings in curved canals using either reciprocating single-or rotary multi-instrument systems and a supplementary step with the XP-Endo Finisher. J Endod. 2016;42:1114-9.