Original Article

Comparison of Apical Debris Extrusion of Different Generation Nickel-Titanium Instrument Systems

AD Uygun

Department of Endodontics, Faculty of Dentistry, Afyonkarahisar Health Sciences University, Afyonkarahisar, Turkey

Received: 10-Jul-2022;
Revision: 04-Oct-2022;
Accepted: 14-Nov-2022;
Published: 20-Dec-2022

Abstract

Background and Aim: The aim of this study is to evaluate the apical debris extrusion amounts and preparation times of four different nickel-titanium systems with a similar cross-section design—Mtwo, RECIPROC, RECIPROC blue, and VDW.ROTATE. **Materials and Methods:** Eighty human mandibular central incisors were divided into four equal groups (n = 20). The test apparatus was inserted into an assembly that provided root canal temperature. Preparation times were recorded using a stopwatch, and the amount of extruded debris was collected in pre-weighed Eppendorf tubes. After drying, the net amount was determined by subtracting the previously measured Eppendorf tube weights from the total weight. **Results:** The Mtwo had the largest amount of debris, but there was no significant difference among the other groups. The VDW.ROTATE completed the preparation in a significantly shorter time than the RECIPROC blue and Mtwo. **Conclusion:** Compared to other files, the Mtwo sequence produced significantly more debris and required significantly more time to complete the whole root canal preparation.

Keywords: *Blue wire, debris extrusion, M-wire, reciprocation, traditional alloy*

Introduction

During chemomechanical preparation, which is one of the most important stages of root canal treatment, debris may exit from the root tip and cause post-operative inflammation and delayed healing of periradicular tissues.[1,2] To date, all rotary instrument systems and techniques have been reported to result in the extrusion of debris through the apical foramen. It has been shown that the design (tip size and taper), alloy, and kinematic factors of rotary instruments affect the amount of apical debris extrusion.[3-5]

Since nickel-titanium (NiTi) rotary instruments were first produced, there have been improvements in the mechanical properties of rotary instrument systems with the advancement of production technology. The first-generation rotary instruments were made of traditional NiTi alloy, but with heat-treatment technology, many parameters, such as flexibility and fracture resistance, were improved over time.[6] RECIPROC (REC; VDW, Munich, Germany), a new-generation NiTi instrument, is a well-known reciprocating single-file system made of M-wire alloy. M-wire alloy is produced using a proprietary thermomechanical procedure. The RECIPROC blue system (RB; VDW) has the same design as REC but is made with a different alloy.[5,7] The alloy of this system is produced via a complex heating–cooling proprietary process, resulting in a visible layer of blue titanium oxide on the surface of the device. The difference between these two systems is that REC is thermally treated before the manufacturing process, while RB is heat treated both before and after. Therefore, RB can pre-bend the instrument.[8] VDW.ROTATE (VR; VDW), another new-generation NiTi instrument system, is a multi-file system designed to be used in different cases and contains files of different tip sizes and tapers.[9] The

Address for correspondence: Dr. AD Uygun, Department of Endodontics, Faculty of Dentistry, Afyonkarahisar Health Sciences University, Afyonkarahisar, 03000, Turkey. E-mail: ademirhan100@hotmail.com

Access this article online

Quick Response Code:

Website: www.njcponline.com

DOI: 10.4103/njcp.njcp_455_22

How to cite this article: Uygun AD. Comparison of apical debris extrusion of different generation nickel-titanium instrument systems. Niger J Clin Pract 2022;25:2010-5.

instruments are used with a continuous rotation motion in a clockwise direction. VR has an S-shaped cross-section like the previously produced Mtwo system (VDW), but it is subjected to a special heat treatment by the manufacturer.[10,11]

The aim of this study is to determine the preparation time and amount of apically extruded debris of the REC and RB single-file NiTi systems and the multiple-file VR and Mtwo NiTi systems, which have similar cross-section designs in terms of the straight root of human mandibular incisors. Many previous studies have been carried out at room temperature, but clinical conditions such as temperature can affect the mechanical properties of the instruments.[12,13] Therefore, this laboratory study was carried out at root canal temperature by imitating the clinical conditions. The null hypothesis was that there is no significant difference between the four above-mentioned systems in terms of the preparation time and the amount of apically extruded debris in human mandibular central incisors at root canal temperature.

Materials and Methods

After obtaining ethics committee approval (2021/246), 80 mandibular central incisor teeth (without premade restoration, immature apices, calcification, caries, or cracks) that had been extracted for periodontal reasons were included. Periapical radiography was used to confirm that the teeth had a single canal and curvature of less than 5%.[14] Before the specimens were used, soft and hard tissue residues were removed from the root surface with a scaler.

The endodontic access cavities were made under water cooling. After the cavities were opened, the lengths were fixed at 16 mm for standardization. The initial apical file was a #15 K-file, which was inserted into the canal until its tip was visible at the major apical foramen under an operating microscope. The working length was calculated by subtracting 1 mm from this length. The width of the apical foramen was in accordance with the #15 file. This was controlled with size 15 and 20 gutta-percha points.

Debris collection

The experimental design outlined by Myers and Montgomery[15] was modified and used to collect apically extruded debris. The Eppendorf tubes and stoppers were separated, and each Eppendorf tube was numbered. The weight of each tube was measured using an electronic analytical balance with an accuracy of 10^{-4} (Axis AGN 220; Axis, Gdansk, Poland). Each tube was measured three times, and the average values were recorded. The stoppers were drilled in the middle, and the teeth were bonded with cyanoacrylate at the cementoenamel junction to prevent leakage. To equalize the internal and external pressure during shaping, the 27-gauge needle tip was placed in the stopper so that the tip of the needle remained in the tube. Eppendorf tubes were placed in a glass bottle so that they would not move and were covered with aluminum foil to block the view of the operator. The test apparatus was inserted into an assembly that provided root canal temperature (35°C ± 2). The samples were randomly divided into four groups ($n = 20$).

- Group 1: Mtwo NiTi instruments were used in a continuous rotary motion according to the manufacturer's instructions. The instrumentation sequence was 10.04, 15.05, 20.06, and 25.06.
- Group 2: REC R25 NiTi instruments were used in a reciprocating motion according to the manufacturer's instructions.
- Group 3: RB R25 NiTi instruments were used in a reciprocating motion according to the manufacturer's instructions.
- Group 4: VR NiTi instruments were used in a continuous rotary motion according to the manufacturer's instructions. The instrumentation sequence was 15.04, 20.05, and 25.06.

Each NiTi instrument in the study shaped only four canals.[7,10] A VDW silver RECIPROC endodontic motor was used in this study. In all groups, the flutes of the instruments were cleaned with cotton gauze each time they were removed from the canal. Preparation time was recorded with the aid of a stopwatch. Root canal irrigation was performed with a 30 gauge NaviTip irrigation needle (Ultradent, South Jordan, UT, USA) after each instrument change in the groups. The needle was positioned 2 mm shorter than the working length and positioned 2 mm shorter than the pinch point when contact was made earlier. In the Mtwo and VR groups, a total of 12 ml of 2.5% NaOCl solution was used for irrigation, divided equally at each instrument change. In the REC and RB groups, the preparation was made with three–four pecking movements of 3 mm amplitude (one in-out movement means one pecking). The preparation was stopped when it was 6 mm (±1) and 3 mm (±1) shorter than the working length, and intermediate irrigations (4 + 4 ml) were performed 2 mm short from the point where the needle was stuck. After the preparation was completed, 4 ml more irrigation was done, thus giving a total of 12 ml 2.5% NaOCl irrigation in the REC and RB groups. With the completion of the final irrigations, the Eppendorf tubes were removed from the glass vial, and the external surface of the roots was washed with 1 ml of distilled water.

To dry the extruded debris, the Eppendorf tubes were placed in an incubator at 70°C for five days. Afterward, the tubes were weighed three times, and the average values were recorded. Net dry debris weight was obtained by subtracting the first measurement from the last measurement.

The amount of apically extruded debris and the preparation time were analyzed statistically using a one-way analysis of variance and Tukey's post hoc test at a significance level of 0.05. SPSS 23.0 (IBM, Armonk, NY, USA) was used for all statistical analyses.

Results

Apical extrusion of debris was observed in all specimens. The Mtwo group produced significantly more debris than the other groups ($P < 0.05$). There was no significant difference between the VR, REC, and RB groups ($P > 0.05$). The mean, standard deviation, minimum and maximum values of the apically extruded debris of each experimental group are shown in Table 1.

When the preparation times were examined, there was no statistical difference between the reciprocation groups (Group 2 and Group 3; $P > 0.05$), but there was a statistical difference between the rotation groups (Group 1 and Group 4; $P < 0.05$). The time to reach the working length of the VR group was significantly less compared to the RB and Mtwo groups ($P < 0.05$). The group with the longest preparation time was Mtwo. The preparation times of the groups are shown in Table 2, and the preparation times of each instrument and the speed and torque setting values used are shown in Table 3.

Table 1: Amount of apically extruded debris of the tested instrument systems in grams

	Mean	SD	Min	Max
Mtwo	0.0015[a]	0.00051	0.0007	0.0024
VDW.ROTATE	0.0007[b]	0.0003	0.0003	0.0012
RECIPROC	0.0009[b]	0.00035	0.0004	0.0016
RECIPROC blue	0.0008[b]	0.00028	0.0005	0.0015

Different superscript letters indicate a significant difference between groups at a 5% significance level

Table 2: Preparation time of the tested NiTi instrument systems in seconds

	Mean	SD	Min	Max
Mtwo	73.3[a]	14.9	51	97
VDW.ROTATE	45.9[b]	9.3	34	68
RECIPROC	48.3[b,c]	7.7	35	62
RECIPROC Blue	55.4[c]	9.1	43	80

Different superscript letters indicate a significant difference between groups at a 5% significance level

Table 3: Preparation time in seconds (Mean±SD), torque (cNm), and speed (rpm) settings of the tested instruments

Instruments	Mean±SD	Torque	Speed
Mtwo 10/0.04	11.6±3	1.2	280
Mtwo 15/0.05	20.9±6.1	1.3	280
Mtwo 20/0.06	30.9±5.9	2.1	280
Mtwo 25/0.06	9.9±3.2	2.3	280
VDW.ROTATE 15/0.04	8.2±2.4	1.3	350
VDW.ROTATE 20/0.05	21.6±4.4	2	350
VDW.ROTATE 25/0.06	16±4.5	2	350
RECIPROC R25	48.3±7.7	-	300
RECIPROC blue R25	55.4±9.1	-	300

Discussion

All instrumentation systems and techniques used to date are known to cause apical extrusion of debris.[16-18] In the current study, the NiTi systems also resulted in a measurable debris output in all samples. The Mtwo group produced more apical debris than the other groups; therefore, the null hypothesis of the study was rejected.

Previous studies have shown that factors such as the kinematics of use, the size, and the design of NiTi files affect the amount of apically extruded debris. A feature of the current study is that all files used have a similar cross-sectional design (S-shaped cross-section) and two active cutting edges.[9,19] However, it has been claimed by the manufacturer that VDW.ROTATE files have an "adapted" S cross-section, and this adapted design for higher cutting efficiency creates more space than the Mtwo file and provides effective debris removal.[20] In our study, the VDW.ROTATE system caused less debris removal than the Mtwo system. Furthermore, the cross-sectional designs and kinematics of the REC and RB systems are the same, except for the alloys. According to the study results, there was no significant difference between the apically extruded debris values of the REC and RB files. However, Doganay and Arslan[5] performed root canal removal in the mesial roots of mandibular molars with root canal filling and reported that REC caused more debris to come out than RB. The researchers stated that this result was due to the improved metallurgy of RB, its greater flexibility, and lower microhardness. There is a difference between the previous study that can be attributed to the using different types of teeth. In one study, it was shown that files with blue alloy preserve apical constriction better in curved canals than M-wire alloy.[21] Therefore, the use of RB files may have resulted in less debris output in curved canals. This difference may not have occurred in the current study due to using teeth with straight canals. As far as we know, there is no other study comparing these two files.

Various studies have examined the debris extrusion of files with the same dimensional design but made with different alloys. Karataş *et al*.[22] and Cakici *et al*.[23] showed that ProTaper Gold files (Dentsply Maillefer, Ballaigues, Switzerland) produced with heat treatment technology cause less debris extrusion than ProTaper Universal files (Dentsply Maillefer, Ballaigues, Switzerland) made with traditional NiTi alloy. According to the literature, gold and blue alloy produced because of heat treatment are defined as martensitic NiTi alloys. The martensitic instruments can be easily deformed due to the reorientation of the martensite variants and show a shape memory effect when heated. The use of martensitic alloy results in more flexible instruments compared with austenitic alloy (traditional).[24] According to these studies, when the other factors (size, design, and kinematics) affecting the debris output are standardized, martensitic instruments cause less debris output than austenitic instruments. In the current study, while there was no difference between the REC, RB, and VR groups, the Mtwo made with traditional NiTi alloy caused more apical debris output. The results of the current study are only in partial agreement with the aforementioned studies due to differences in experimental methodology.

The main difference between the experimental methodology of these studies and the current study is the ambient temperature. A previous study investigating the effect of temperature on the collagen-dissolving ability of an endodontic irrigant claimed that the root canal temperature was 31°C–33.5°C.[25] Subsequently, de Hemptinne *et al*.[26] stated that the root canal temperature was 35.1°C on average. In the current study, the samples were kept in an incubator before preparation to better simulate the clinical conditions, and the study was carried out by placing the test apparatus in water at 35°C. Moreover, most debris studies in the literature use distilled water for irrigation.[27-29] The reason for using distilled water instead of sodium hypochlorite is that sodium hypochlorite is not sterile, and its content and crystallization differ.[16,30] However, distilled water has no tissue-dissolving activity and does not reflect clinical practice. For this reason, 2.5% sodium hypochlorite was used in this study to better simulate clinical conditions.

There are different results in the literature regarding the debris generated by kinematics.

It has been claimed that systems operating with reciprocal motion cause more debris outflow than systems operating with continuous rotational motion.[7,10] However, there are studies that claim the opposite.[4,31,32] There is no consensus in the literature on this issue. The researchers noted that these contrasting results might be due to different experimental methodologies, analytical balance sensitivity, teeth, initial preparations, and comparison of different systems with different size files. Predin Djuric *et al*.[27] used the same NiTi files in both reciprocation and rotation according to cutting direction (clockwise and counterclockwise) and showed that kinematics did not make a significant difference in terms of apically extruded debris. Consistent with these results, kinematics cannot be said to have a significant effect on debris in the current study. In terms of apical debris output, the groups used with reciprocal kinematics caused less debris output than the Mtwo group used with rotation, while there was no significant difference between them and the VR group.

One difference between the groups in the study was the number of instruments used to complete the preparation. De-Deus *et al*.[33] compared the use of a multi-file system, Protaper Universal (Dentsply Maillefer, Ballaigues, Switzerland) (S1, SX, S2, F1, and F2) with the conventional technique, with the use of the same system only with the F2 file and reported that the number of instruments did not affect the apical debris extrusion. In studies examining the effect of NiTi file systems on debris extrusion, there are different results regarding the superiority of single or multiple file systems.[7,10,31] Similarly, there are different results in the literature regarding the effect of finishing the preparation with more files using glide path files before single file systems on the debris extrusion.[34,35]

When the studies in terms of taper are examined, it cannot be said that the high or low taper directly affects the debris output because there are many non-constant parameters such as tip size, file usage speed, torque, kinematics, and a number of files since different NiTi file systems were compared in previous studies. However, Aksel *et al*.[36] investigated the effect of files with different tapers of the "K3" (SybronEndo, West Collins, CA) NiTi system on bacterial debris extrusion. In groups prepared with the crown-down shaping technique, it was reported that the file with 0.02 taper caused less debris output compared to files with 0.04 and 0.06 taper. In contrast, in the full-length linear instrumentation technique, there was no statistical difference between files with different angles. In the current study, while there is no difference between single file systems with 0.08 taper and VR with 0.06 taper, there is a statistically significant difference between Mtwo with 0.06 taper and the other files. Moreover, an important difference that should be noted regarding the taper of the files used in the study is that Mtwo and VDW.ROTATE systems have a constant taper, while the REC and RB systems have a variable taper. REC and RB are said to have 0.08 tapers in the apical 3 mm region, followed by a decline.[37,38] Based on the results of the current study, it can be assumed that the taper and number of instrument factors do not have a direct effect on the debris output.

Few of the debris studies in the literature shared information on preparation times. Dincer *et al*.[39] reported that REC had a shorter total retreatment time than Mtwo in their study in which they examined the debris extrusion in the retreatment procedure. Bürklein and Schäfer[7] and Bürklein *et al*.[10] reported that REC completed the preparation in a significantly shorter time than Mtwo. In terms of preparation times, the current study is in agreement with these results. Also, in line with the methodology of these two studies,[7,10] in the current study, each instrument was used to shape only four canals. Using one instrument per canal may possibly alter these results. Therefore, further research is needed on preparation time. In a different study, Romeiro *et al*.[40] obtained the retreatment time of REC and RB files in canals filled with two different sealers, using one instrument per tooth. As a result of the aforementioned study, there was no difference between REC and RB in canals filled with bioceramic sealer, while REC prepared in a shorter time than RB in canals filled with a resin-containing sealer. As a result of our study, no statistical difference was found between the REC and the newer RB and VR systems made with blue alloy. The difference between VR and RB with the same alloy is likely due to the lower taper of VR. REC, RB, and VR systems with heat-treated alloys completed the preparation in a shorter time than the Mtwo system made from conventional alloy and caused less debris extrusion. Additionally, the preparation time can be affected by the rpm and torque values. All files in the study were used in the settings in the manufacturer's instructions [Table 3]. The Mtwo system, which has lower torque and rpm values according to the manufacturer's instructions, completed the preparation in a long time.

The limitation of this study is that the method used does not fully reflect the clinical situation. In the current study, the method presented by Myers and Montgomery[15] is used by modifying the canal temperature. However, this method, which has been used in apical debris extrusion studies for many years, does not mimic vital periapical tissues and their back pressures. Therefore, although different techniques using floral foam and agar have been proposed by some researchers, these techniques have several drawbacks, such as absorption of the foam and difficulty in determining an exact value of the agar gel thickness at the apex to mimic the size of the apical lesion.[41,42] In addition, Tanalp and Güngör[16] reported that the difference in dentin microhardness might affect the results of the studies. Due to these limitations, studies of apical debris extrusion using extracted teeth do not reflect the clinical situation. Therefore, clinical studies examining postoperative pain or the incidence of flare-ups are needed to make more accurate conclusions about the clinical success of these files.

Conclusions

It was concluded that, within the limitations of the present study, the Mtwo system made of conventional NiTi alloy caused the highest debris output statistically, while there was no difference between the other groups. In addition, when the preparation times were examined, the Mtwo group had the highest values. The VR group had significantly lower values than the RB group, and there was no difference between them and the REC group.

Author contributions

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Seltzer S, Naidorf IJ. Flare-ups in endodontics: I. Etiological factors. J Endod 1985;11:472-8.
2. Siqueira JF, Jr. Microbial causes of endodontic flare-ups. Int Endod J 2003;36:453-63.
3. Kocak S, Kocak MM, Saglam BC, Türker SA, Sağsen B, Er Ö. Apical extrusion of debris using self-adjusting file, reciprocating single-file, and 2 rotary instrumentation systems. J Endod 2013;39:1278-80.
4. Arslan H, Doganay E, Alsancak M, Çapar ID, Karataş E, Gündüz HA. Comparison of apically extruded debris after root canal instrumentation using Reciproc instruments with various kinematics. Int Endod J 2016;49:307-10.
5. Doğanay Yıldız E, Arslan H. The effect of blue thermal treatment on endodontic instruments and apical debris extrusion during retreatment procedures. Int Endod J 2019;52:1629-34.
6. Haapasalo M, Shen Y. Evolution of nickel–titanium instruments: From past to future. Endod Topics 2013;29:3-17.
7. Bürklein S, Schäfer E. Apically extruded debris with reciprocating single-file and full-sequence rotary instrumentation systems. J Endod 2012;38:850-2.
8. Gavini G, Santos Md, Caldeira CL, de Lima Machado ME, Freire LG, Iglecias EF, *et al*. Nickel–titanium instruments in endodontics: A concise review of the state of the art. Braz Oral Res 2018;32(Suppl 1):e67.

9. Uygun AD. Cyclic fatigue resistance of VDW. ROTATE and reciproc blue nickel-titanium files at root canal temperature. J Dent Res Dent Clin Dent Prospects 2020;14:177-80.
10. Bürklein S, Benten S, Schäfer E. Quantitative evaluation of apically extruded debris with different single-file systems: R eciproc, F 360 and O ne S hape versus M two. Int Endod J 2014;47:405-9.
11. Keskin C, Yilmaz ÖS, Keleş A, Inan U. Comparison of cyclic fatigue resistance of Rotate instrument with reciprocating and continuous rotary nickel–titanium instruments at body temperature in relation to their transformation temperatures. Clin Oral Investig 2021;25:151-7.
12. De Vasconcelos RA, Murphy S, Carvalho CAT, Govindjee RG, Govindjee S, Peters OA. Evidence for reduced fatigue resistance of contemporary rotary instruments exposed to body temperature. J Endod 2016;42:782-7.
13. Plotino G, Grande NM, Bellido MM, Testarelli L, Gambarini G. Influence of temperature on cyclic fatigue resistance of ProTaper Gold and ProTaper Universal rotary files. J Endod 2017;43:200-2.
14. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol Oral Radiol 1971;32:271-5.
15. 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.
16. Tanalp J, Güngör T. Apical extrusion of debris: A literature review of an inherent occurrence during root canal treatment. Int Endod J 2014;47:211-21.
17. Romualdo PC, de Oliveira KMH, Nemezio MA, Küchler EC, Silva RAB, Nelson-Filho P. Does apical negative pressure prevent the apical extrusion of debris and irrigant compared with conventional irrigation? A systematic review and meta-analysis. Aust Endod J 2017;43:129-37.
18. Al Omari T, El-Farraj H, Arıcan B, Atav Ateş A. Apical debris extrusion of full-sequenced rotary systems in narrow ribbon-shaped canals. Aust Endod J 2022;48:245-50.
19. Kim H, Kim H, Lee C, Kim BM, Park JK, Versluis A. Mechanical response of nickel–titanium instruments with different cross-sectional designs during shaping of simulated curved canals. Int Endod J 2009;42:593-602.
20. VDW.ROTATE brochure. Available from: https://www.vdw-dental.com/fileadmin/Dokumente/Sortiment/Aufbereitung/Rotierende-Aufbereitung/ROTATE/VDW-Dental-ROTATE-Product-Broschure-1-EN.pdf. [Last accessed on 2022 Oct 04].
21. Pacheco-Yanes J, Gazzaneo I, Pérez AR, Armada L, Neves MAS. Transportation assessment in artificial curved canals after instrumentation with reciproc, reciproc blue, and XP-endo shaper systems. J Investig Clin Dent 2019;10:e12417.
22. Karataş E, Ersoy İ, Gündüz HA, Uygun AD, Kol E, Çakıcı F. Influence of instruments used in root canal preparation on amount of apically extruded debris. Artif Organs 2016;40:774-7.
23. Cakici F, Cakici EB, Küçükekenci FF, Uygun AD, Arslan H. Apically extruded debris during root canal preparation using ProTaper Gold, ProTaper Universal, ProTaper next, and RECIPROC instruments. Int J Artif Organs 2016;39:128-31.
24. Zupanc J, Vahdat-Pajouh N, Schäfer E. New thermomechanically treated NiTi alloys–a review. Int Endod J 2018;51:1088-103.
25. Cunningham WT, Balekjian AY. Effect of temperature on collagen-dissolving ability of sodium hypochlorite endodontic irrigant. Oral Surg Oral Med Oral Pathol Oral Radiol 1980;49:175-7.
26. de Hemptinne F, Slaus G, Vandendael M, Jacquet W, De Moor RJ, Bottenberg P. *In vivo* intracanal temperature evolution during endodontic treatment after the injection of room temperature or preheated sodium hypochlorite. J Endod 2015;41:1112-5.
27. Predin Djuric N, Van Der Vyver P, Vorster M, Vally ZI. Comparison of apical debris extrusion using clockwise and counter-clockwise single-file reciprocation of rotary and reciprocating systems. Aust Endod J 2021;47:394-400.
28. Karataslioglu E, Arslan H, Er G, Avci E. Influence of canal curvature on the amount of apically extruded debris determined by using three-dimensional determination method. Aust Endod J 2019;45:216-24.
29. Düzgün S, Topçuoğlu HS, Kahraman Ö. Evaluation of apically extruded debris during the canal preparation using new heat-treated nickel-titanium files in curved canals. Aust Endod J 2021;47:54-8.
30. Ozlek E, Neelakantan P, Khan K, Cheung GSP, Rossi-Fedele G. Debris extrusion during root canal preparation with nickel-titanium instruments using liquid and gel formulations of sodium hypochlorite in vitro. Aust Endod J 2021;47:130-6.
31. De-Deus G, Neves A, Silva EJ, Mendonça TA, Lourenço C, Calixto C, *et al*. Apically extruded dentin debris by reciprocating single-file and multi-file rotary system. Clin Oral Investig 2015;19:357-61.
32. Silva E, Carapiá M, Lopes R, Belladonna FG, Senna PM, Souza EM, *et al*. Comparison of apically extruded debris after large apical preparations by full-sequence rotary and single-file reciprocating systems. Int Endod J 2016;49:700-5.
33. De-Deus G, Brandão MC, Barino B, Di Giorgi K, Fidel RAS, Luna AS. Assessment of apically extruded debris produced by the single-file ProTaper F2 technique under reciprocating movement. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010;110:390-4.
34. Topçuoğlu H, Düzgün S, Akpek F, Topçuoğlu G, Aktı A. Influence of a glide path on apical extrusion of debris during canal preparation using single-file systems in curved canals. Int Endod J 2016;49:599-603.
35. Gunes B, Yeter KY. Effects of different glide path files on apical debris extrusion in curved root canals. J Endod 2018;44:1191-4.
36. Aksel H, Eren SK, Çakar A, Serper A, Özkuyumcu C, Azim AA. Effect of instrumentation techniques and preparation taper on apical extrusion of bacteria. J Endod 2017;43:1008-10.
37. Reciproc Blue brochure. Available from: https://www.vdw-dental.com/fileadmin/Dokumente/Sortiment/Aufbereitung/Reziproke-Aufbereitung/RECIPROC-blue/VDW-Dental-RECIPROCblue-User-Brochure-EN.pdf. [Last accessed on 2022 Oct 04].
38. Arias A, Perez-Higueras JJ, José C. Differences in cyclic fatigue resistance at apical and coronal levels of Reciproc and WaveOne new files. J Endod 2012;38:1244-8.
39. Dincer A, Er O, Canakci B. Evaluation of apically extruded debris during root canal retreatment with several NiTi systems. Int Endod J 2015;48:1194-8.
40. Romeiro K, de Almeida A, Cassimiro M, Gominho L, Dantas E, Chagas N, *et al*. Reciproc and reciproc blue in the removal of bioceramic and resin-based sealers in retreatment procedures. Clin Oral Investig 2020;24:405-16.
41. Altundasar E, Nagas E, Uyanik O, Serper A. Debris and irrigant extrusion potential of 2 rotary systems and irrigation needles. Oral Surg Oral Med Oral Pathol Oral Radiol Endodontol 2011;112:e31-5.
42. Lu Y, Wang R, Zhang L, Li HL, Zheng QH, Zhou XD, *et al*. Apically extruded debris and irrigant with two N i-T i systems and hand files when removing root fillings: A laboratory study. Int Endod J 2013;46:1125-30.