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Efficacy of Laser Activated Irrigation on Apically Extruded Debris with Different Preparation Systems

Alper Kuştarcı, DDS, PhD, and Kürşat Er, DDS, PhD

Abstract

Objective: The aim of this study was to evaluate apical extrusion of debris in canals prepared with three nickel-titanium (NiTi) rotary file systems [Twisted File Adaptive (TFA), SybronEndo, Orange, CA], Reciproc [(RP), VDW, Munich, Germany], and Revo-S [(RS), MicroMega, Besançon, France] and two irrigation [conventional needle (CNI) and laser-activated (LAI)] techniques. ***Background data:*** Although previous studies have evaluated the amount of apically extruded debris by various instrumentation and irrigation methods, none of them have investigated the effect of LAI during the root canal preparation on debris extrusion. ***Methods:*** Ninety extracted single-rooted human mandibular premolars with straight canals were randomly assigned to six groups ($n = 15$) according to the file and irrigation protocols used: (1) TFA and LAI group, (2) RP and LAI group, (3) RS and LAI group, (4) TFA and CNI group, (5) RP and CNI group, and (6) RS and CNI group. Debris extruded from the apical foramen during root canal preparation was collected into preweighed Eppendorf tubes. The weight of the dry extruded debris was established by subtracting the preinstrumentation and postinstrumentation weight of the Eppendorf tubes for each group. Data were analyzed using the Kruskal Wallis and Mann Whitney *U* tests with Bonferroni correction to compare groups. ***Results:*** LAI groups extruded more debris than CNI groups ($p < 0.05$). However, no statistically significant differences were observed among the file groups when each irrigation method was evaluated separately ($p > 0.017$). ***Conclusions:*** Within the limitations of this study, it can be concluded that the agitation method, such as LAI, had a significant effect on the amount of extrusion.

Introduction

Cleaning of the root canal system using files and irrigation solutions is important for improving the success of endodontic treatment. However, debris chips, pulp tissue, irrigants, microbiota, and their byproducts may be extruded beyond the apex during this procedure. Extrusion of these materials may cause consequences, such as induction of inflammation and postoperative pain and delay of periapical healing;[1] therefore, the extrusion root canal ingredients beyond the apical foramen is undesired during root canal treatment.

All the preparation methods have showed varying degrees of extrusion,[2–7] attributed to various factors such as root canal anatomy, irrigation method, amount/flow rate, penetration depth of irrigant, and selected file type or instrumentation method. Common findings showed that methods involving a push-pull filing motion usually create a greater debris extrusion than engine-driven rotary motion.[4] This is because the design of the rotary files along with the motion used tends to pack dentinal debris into flutes of files and direct it coronally toward the orifice. This minimizes the compaction of debris in the root canal.[8]

Various nickel-titanium (NiTi) rotary files have been developed to shape the root canals. To improve safety preparation and to prepare intended shapes, new file designs with noncutting tips, radial lands, varying tapers and rake angles, and changing pitch lengths have been developed. One of them is the Reciproc (RP) (VDW, Munich, Germany) system, which has been designed to completely prepare and clean the root canals with only one file and reciprocating motion.[9] This motion relieves stress on the file by special counterclockwise (cutting action) and clockwise (release of the file) movements and, therefore, reduces the risk of cyclic fatigue caused by tension and compression.[10] Also, the files of this system are manufactured with M-Wire technology to improve flexibility and resistance to cyclic fatigue.[11]

The Twisted File Adaptive (TFA) (SybronEndo, Orange, CA) system is a novel file that uses a combined continuous rotation and a reciprocating motion. The file uses continuous rotation when the file is exposed to minimal or no force applied while using a reciprocal motion when it engages dentin or load is applied. Manufacturers claimed that this adaptive technology and twisted file design, using R-phase treatment, increases debris removal and flexibility and reduces the risk of intracanal

Department of Endodontics, Faculty of Dentistry, Akdeniz University, Antalya, Turkey.

failure, such as instrument fracture, ledge formation, zipping, stripping, or perforations, without affecting performance.[6,12]

Although shaping of the root canal has been improved with advances in metal technology, cleaning of the canal still relies heavily on the adjunctive use of chemical rinsing and soaking solution because of the anatomical complexity and irregularity of root canal system.[13] Needle irrigation is the conventional method for irrigation, and the level of needle tip placement in the canal is the most important factor for solution penetration, because the performance of irrigation usually depends upon the ability of the irrigant to penetrate the full extent of the root canal system.[14] However, the conventional needle irrigation (CNI) method is, unfortunately, insufficiently effective in the apical third of the root canal.[15] As a consequence, sonic, ultrasonic, and laser activation of irrigating solutions has been developed to improve their chemical and mechanical effectiveness during the root canal treatment.[16]

In recent years, laser activated irrigation (LAI) with pulsed middle infrared erbium: yttrium-aluminium-garnet (Er:YAG) and erbium chromium: yttrium-scandium-gallium-garnet (Er,Cr:YSGG) lasers has been introduced as a method for activating the irrigants. The effect is based on cavitation; in irrigants, activation of the laser at subablative settings may result in the formation of large elliptical vapor bubbles, which expand and implode. When the bubble implodes after 100–200 μs, an under pressure develops and sucks fluid back into the canal, inducing secondary cavitation effects.[17] In the LAI method, irrigants are also used during lasing to reduce thermal side effects to the radicular dentine and periodontium.

Previous studies[4,6,7,18,19] have evaluated the amount of apically extruded debris by various instrumentation and irrigation methods. However, none of them have investigated the effect of LAI during the root canal preparation on debris extrusion. Therefore, the aim of this study was to compare the effects of three file systems [TFA, RP, and Revo-S (RS)], and two irrigation techniques (CNI and LAI) on the amount of apically extruded debris.

Material and Methods

Selection and preparation of teeth

Ninety freshly extracted single-rooted human mandibular premolars with fully formed apices were selected in this study. All the teeth were analyzed radiographically to confirm the root canal anatomy. The inclusion criteria were single-rooted mandibular premolar teeth with one root canal and one apical foramen; root curvature between 0 and 10 degrees; no signs of cracks, internal or external resorption, root caries, calcification, or open apices; and size of the minor constriction was not gauged larger than #15 K-file. Soft-tissue remnants and calculi on the external root surface were removed mechanically. The teeth were immersed in 0.5% chloramine-T solution for 48 h for disinfection. Then these samples were stored in 4°C distilled water until use.

The samples were decoronated to obtain a standardized root length of 17 mm using a diamond disc. The working length (WL) was determined by subtracting 1 mm from the length at which the tip of a #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) extruded apically. The teeth were randomly divided into six experimental groups ($n = 15$) according to the file and irrigation systems used for preparation of root canals.

Test design

To evaluate the apically extruded debris collection, a similar experimental method as described by Myers and Montgomery[20] was used (Fig. 1A). A hole was created on each Eppendorf tube stopper, and each tooth was inserted under pressure through the stopper, which was fixed by an adhesive (Pattex Super Glue; Turk Henkel, Istanbul, Turkey). The apical part of the root was suspended within the tube, which acted as a collecting container for apical material evacuated through the foramen of the root. A 27 gauge open-ended needle was inserted into each Eppendorf tube stopper to balance the air pressure between the inside and outside of the tube. Then, each stopper, including the tooth and needle, was fitted into the Eppendorf tube. The tube was fitted into a vial to hold the device during instrumentation. All vials were covered with aluminum leaf to prevent the operator from viewing debris extrusion. In no case was the inner Eppendorf tube touched with fingers.

Preweighing of the Eppendorf tubes

Empty Eppendorf tubes without stoppers were weighed with an electronic balance (Precisa; Precisa Inst., Dietikon, Switzerland) with an accuracy of 10^{-5} precision. Three consecutive measurements were taken for each tube, and the mean weight was calculated.

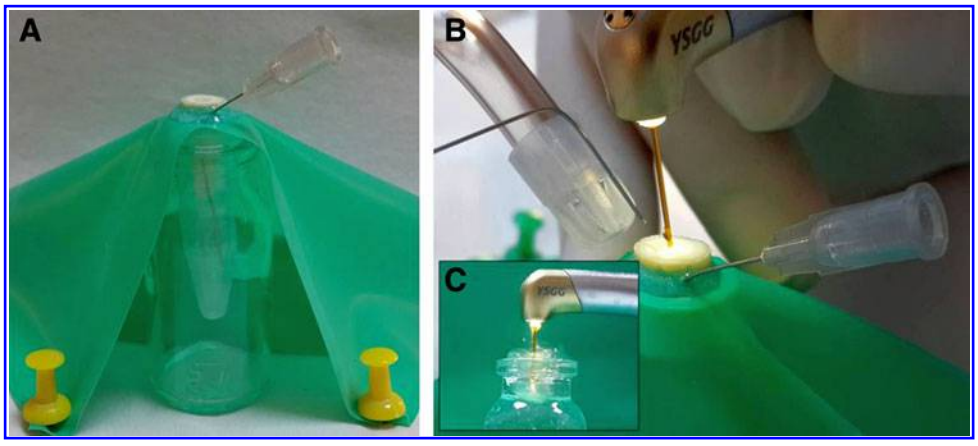


FIG. 1. **(A)** Test design, **(B)** laser application, **(C)** cavitation effect of laser.

Irrigation procedures

In each sample, the total activation time was 1 min, and a total volume of 8 mL bidistilled water was used as the irrigation solution after each file or after 3 pecks using the reciprocating files (as recommended by the manufacturers). Two irrigation methods were used.

Parameters and procedures of LAI

An Er,Cr:YSGG laser system (2780 nm wavelength; Biolase Waterlase MD, Biolase Technology, Irvine, CA) was used at a panel setting of 0.5 W at 20 Hz (25 mJ/pulse) with no air or water. The pulses were focused using a fiber tip [Radio Firing Perio Tip (RFPT)5] with a diameter of 580 μm and a length of 14 mm. The root canals were irrigated in a passive manner with 0.3 mL of bidistilled water, and the optical fiber was placed at the entrance of the root canal orifice and activated. During the laser irradiation cycles, root canals were continuously irrigated to maintain hydration levels using a hand syringe with a 27 gauge open-ended needle positioned above the laser tip in the coronal aspect of the access opening (Fig. 1B).

Parameters and procedures of CNI

The teeth were irrigated with bidistilled water using a 27 gauge open-ended needle. To standardize the irrigation protocol, the needle was inserted into the canal within 2 mm of the WL without binding and was moved in an up-and-down motion.

The groups were distributed according to the instrumentation and irrigation systems used.

Group 1 (TFA and LAI group). The files were used with the TFA program of their motor in the sequence of SM1 (20/0.04) and SM2 (25/0.06) (full WL). The file was advanced to the canal with a single controlled motion until the file engaged dentin. The LAI was applied during each file change, according to the above-described protocol.

Group 2 (RP and LAI group). An R25 (25/.08) RP file was used with the RP program of its motor in a reciprocating, slow, in-and-out pecking motion according to the manufacturer's instructions. The flutes of the file were cleaned after three in-and-out movements (pecks). The LAI was applied between the pecking sequences, according to the above protocol.

Group 3 (RS and LAI group). RS files were used with a slow and unique downward movement in a free progression without pressure at 300 rpm. The instrumentation sequence was SC1 file (25/0.06) at two thirds of the WL and SC2 (25/0.04) and SU files (25/0.06) at the WL. Irrigation was performed in the same manner as for the TFA and LAI group.

Group 4 (TFA and CNI group). Instrumentation was performed in the same way as for the TFA and LAI group. The teeth were irrigated with a 27 gauge open-ended needle during each file change, according to the above-described protocol.

Group 5 (RP and CNI group). Instrumentation was performed in the same way as for the Reciproc and LAI groups. The teeth were irrigated with a 27 gauge open-ended needle between the pecking sequences, according to the above-described protocol.

Group 6 (RS and CNI group). Instrumentation was performed in the same way as for the Revo S and LAI groups. Irrigation was performed in the same manner as for the TFA and CNI groups.

During the instrumentation procedure, the teeth were isolated with a rubber dam to prevent irrigation solution extrusion through the hole. An aspirator was used to suction the irrigating solution that overflowed from the tooth crown. To avoid variation and to eliminate biases, the cleaning, shaping, and irrigation procedures were performed by a single operator (A.K.), and evaluation was performed by a second examiner (K.E.) who was blind to the group assignment.

Postweighing of the Eppendorf tubes

After completion of the instrumentation, the stoppers of the vial and Eppendorf tubes were removed. The surface of the root was washed with 1 mL bidistilled water into the vial to collect the debris adhering to the root surface. The tubes were then stored in an incubator at 55°C for 10 days for evaporation of the distilled water, before weighing the dry debris. The Eppendorf tubes were weighed using the same analytical balance to obtain the final weight of the tubes including the extruded debris. Three consecutive weights were obtained for each tube. The net weight of the extruded debris was determined by subtracting the initial weight from the final weight.

Statistical analysis

All statistical analyses were performed using SPSS software (SPSS Inc, Chicago, IL). Kolmogorov–Smirnov tests showed the data were not normally distributed; therefore, nonparametric Kruskal Wallis and Mann Whitney *U* tests with Bonferroni correction were used to compare the groups.

Results

The mean and standard deviation values for all groups are listed in Table 1. The results indicate that all file and irrigation systems caused measurable apical extrusion of debris. A comparison of the results obtained with the three instrumentation methods revealed that the amount of debris extruded apically by LAI was significantly greater than that extruded by CNI ($p < 0.05$). However, no statistically significant differences were observed among the file groups when each irrigation method was evaluated separately ($p > 0.017$).

Discussion

The results of this study show that apical extrusion of debris is inevitable during preparation of root canal systems, regardless of the type of file, instrumentation, or irrigation method used. We compared the amount of debris that was apically extruded while using three different NiTi file systems with different designs, manufacturing methods, numbers, and kinematics (i.e., reciprocating, continuous rotation, and combined reciprocating-rotation motions). No statistically significant difference was found among the instrumentation systems (RP, TFA, and RS), regardless of the irrigation technique employed.

Table 1. Amount of Debris Extruded Apically After Using the Different Instruments and Irrigation Systems (g)

Debris extrusion (g)	*TFA/LAI*	*RP/LAI*	*RS/LAI*	*TFA/CNI*	*RP/CNI*	*RS/CNI*
Mean	0.000410[a]	0.000398[a]	0.000496[a]	0.000088[b]	0.000097[b]	0.000138[b]
Standard deviation	0.000248	0.000286	0.000277	0.000053	0.000079	0.000110
Number of samples	15	15	15	15	15	15
Minimum	0.00008	0.00006	0.00011	0.00001	0.00001	0.00003
Maximum	0.00096	0.00102	0.00112	0.00020	0.00029	0.00045

Different superscript letters indicate a significant difference between groups.
TFA, Twisted File Adaptive; LAI, laser-activated irrigation; RP, Reciproc; RS, Revo-S; CNI, conventional needle irrigation.

Every preparation system has inherent clinical advantages and disadvantages in relation to its properties. The design of rotary NiTi files along with the motion used tends to direct debris toward the canal orifice. Further, early flaring of the coronal part of the preparation may improve file control during preparation of the apical third of the canal.[8] However, rotary NiTi systems use multiple files for root canal preparation compared with reciprocating files. Therefore, the longer instrumentation time needed with rotary NiTi systems may increase the amount of debris that is extruded apically.

In a previous study,[21] less debris extrusion was achieved by the balanced-force method than with methods involving a linear filing motion. Reciprocating motion is similar to the balanced-force method, because the counterclockwise angle is greater than the clockwise movement, causing the file to move continuously toward the apex.[22] However, the reciprocating method uses a single file with an increased taper, such as 25/0.08, in order to reach the apex. Therefore, a reciprocating file with a noncutting tip needs more inward pressure for progressing toward the apex than does a similar-sized rotary NiTi file, and this pressure may push the debris toward the apex.[23] In addition, the cutting ability of a reciprocating file is smaller than that of a rotary NiTi file; consequently, the debris removal is lower, therefore increasing the frictional stress and torque demand, owing to entrapment of debris within the flutes.[24]

This observation is in agreement with that of a previous study[7] reporting that similar amounts of debris extrusion were observed after instrumentation with the multiple-file rotary NiTi and a single-file reciprocating system. However, the results of the present study do not conform to those of a few other studies,[25–27] which report that multiple-file rotary NiTi instrumentation was associated with reduced[25,26] or increased[27] levels of debris extrusion in comparison with single-file reciprocating systems. The contrast between these outcomes may be explained by the difference in the method of instrumentation, movement kinematics, number of files used, instrument design, apical taper, size of the instrument, selection of teeth, experimental setup, and, more importantly, operator-related variables.

The TFA system has been proposed in order to maximize the advantages of reciprocation while minimizing its disadvantages by using a unique, patented motion and a three file method. Whereas the RP system uses a reciprocation movement only, the TFA system predominantly uses a rotary movement. Further, the TFA system uses a reciprocating movement only when the file finds too much resistance against the dentinal walls.[28] Whereas a review of the literature revealed that no study has evaluated the extent of apically extruded debris during root canal treatment with either TFA or Reciproc systems, only one study compared the TFA system with WaveOne, another reciprocating file system[28] and reported no significant difference between the two systems. The results of the present study corroborate these findings. In contrast, Gambarini et al.[29] concluded from their clinical study that the WaveOne system caused more postoperative pain compared with the TFA and Twisted File systems. However, the preparation systems that we compared in the present study are different from Gambarini et al.'s[29] clinical study. Therefore, assessment of the clinical performance of these systems is necessary for further discussion.

The results of the present study revealed that there is no significant difference between the TFA and RS systems. This could probably be explained by the same apical size and taper (25/0.06), apart from the similar kinematics (continuous rotation and combined reciprocating-rotation motions) of both files. Further, our results are in agreement with those of a previous study reporting that similar levels of debris extrusion were observed after instrumentation with the multiple-file rotary NiTi (ProTaper Next) and TFA systems of the same apical size and taper.[6]

Irrigation is a necessary and important phase in cleansing the canal. In this study, 8 mL of bidistilled water was used in each tooth. Considering the importance of obtaining accurate measurements, completely pure bidistilled water was used to prevent the presence of particulate matter, which is found in other irrigants, from skewing the final values. Therefore, the weights of the tubes in both situations (without distilled water and after drying) were similar, and the debris extrusion effects of rotary NiTi files and manual instrumentation could be accurately investigated. However, it remains open to question whether the use of NaOCl, chlorhexidine (CHX) and/or ethylenediaminetetraacetic acid (EDTA) instead of bidistilled water would have positively impacted the amount of extruded debris.

In this study, a 27 gauge open-ended needle was used for irrigation. Open-ended needles have been reported to result in significantly greater extrusion of irrigants than have closed-ended needles, which could be explained by the greater amount of irrigant pressure developed at the apical foramen.[30] Further, the depth of placement of the needle tip is an important factor in root canal irrigation. It has been recommended that the needle tip be placed 2 mm short of the WL or slightly coronal to that point when resistance is encountered before the needle tip reaches the desirable position.[6] Therefore, in the present study, uniform needle penetration depth was used and the solution was delivered slowly, without binding the needle to the root canal walls.

In the present study, both CNI and LAI were used along with different preparation methods. Although it is advisable to use LAI after each file for debriding and decontamination of the

endodontic system,[31] in most studies, LAI was used with different objectives, only after completion of the root canal preparation.[32–35] Furthermore, these studies did not report the amount of debris extruded apically when LAI was used after each file during the root canal preparation. Therefore, the present study is the first to evaluate the effect of LAI on apically extruded debris after each file or three pecking motions.

In our study, a significant difference was observed between the two irrigation methods: LAI extruded more debris than CNI. This difference could be explained by the cavitation and pressure waves produced by laser activation of the irrigant in the canal (Fig. 1C). Cavitation is defined as the formation of vapor or a cavity that contains bubbles inside a fluid.[36] In water, use of a laser at ablative settings can result in the formation of large elliptical bubbles. These vapor bubbles can cause an expansion of the irrigant by up to 1600 times the original volume.[37] This expansion is the mechanism that generates high pressure that can facilitate three-dimensional (3D) movement of the irrigation solutions, which might assist in cleaning the root canals.[33] Hence, we opine that this high pressure could cause more aggressive irrigation, which could explain the larger quantity of debris extruded apically by LAI.

The distance between the fiber tip and the apex may affect the apical fluid pressure during laser activation with continuous irrigation in the root canal.[38] In the present study, to avoid some of the undesirable effects of the conventional laser applications, the fiber tip of the laser was used only in the coronal part of the root canals for LAI, as in some previous studies.[31,35,39] Unfortunately, despite this, LAI caused significantly more debris extrusion than CNI.

Periapical tissues may serve as a physical barrier and inhibit extrusion of debris clinically. Salzgeber and Brilliant[14] demonstrated that vital tissues help to control the apical and lateral penetration of an irrigating solution. Another study showed that no apical extrusion of the irrigant occurred beyond the apical constriction during LAI *in vivo* by the Er,Cr:YSGG laser.[39] In our study, there was no periapical tissue that could act as a barrier against the apical extrusion of debris. This fact limits the extrapolation of our results to the clinical environment, which is considered a shortcoming in most extrusion studies.[4,5,21,28]

In the present study, independent of the system used, all instrumentation and irrigation methods caused debris extrusion. However, LAI caused more debris extrusion than CNI. We opine that if laser activation is performed for a longer duration using higher power, debris extrusion may increase. Therefore, the optimal laser activation time and other parameters need to be investigated in order to ensure minimal extrusion of debris and of the irrigant caused by cavitation and pressure during root canal treatment.

Author Disclosure Statement

No competing financial interests exist.

References

1. Seltzer S, Naidorf IJ. Flare-ups in endodontics. I. Etiological factors. J Endod 1985;11:472–478.
2. Er K, Sümer Z, Akpınar KE. Apical extrusion of intracanal bacteria following use of two engine-driven instrumentation techniques. Int Endod J 2005;38:871–876.
3. Kuştarcı A, Akpınar KE, Sümer Z, Er K, Bek B. Apical extrusion of intracanal bacteria following use of various instrumentation techniques. Int Endod J 2008;41:1066–1071.
4. Kustarci A, Akpınar KE, Er K. Apical extrusion of intracanal debris and irrigant following use of various instrumentation techniques. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;105:257–262.
5. Kustarci A, Altunbas D, Akpınar KE. Comparative study of apically extruded debris using one manual and two rotary instrumentation techniques for endodontic retreatment. J Dent Sci 2012;7:1–6.
6. Capar ID, Arslan H, Akcay M, Ertas E. 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: 1638–1641.
7. Koçak S, Koçak MM, Sağlam 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;39:1278–1280.
8. Beeson TJ, Hartwell GR, Thornton JD, Gunsolley JC. Comparison of debris extruded apically in straight canals: conventional filing versus Profile.04 Taper Series 29. J Endod 1998;24:18–22.
9. Gutmann JL Gao Y. Alteration in the inherent metallic and surface properties of nickel-titanium root canal instruments to enhance performance, durability and safety: a focused review. Int Endod J 2012;45:113–128.
10. Varela–Patiño P, Ibañez–Párraga A, Rivas–Mundiña B, Cantatore G, Otero XL, Martin–Biedma B. Alternating versus continuous rotation: a comparative study of the effect on instrument life. J Endod 2010;36:157–159.
11. Al-Hadlaq SM, Aljarbou FA, AlThumairy RI. Evaluation of cyclic flexural fatigue of Mwire nickel-titanium rotary instruments. J Endod 2010;36:305–307.
12. Capar ID, Ertas H, Ok E, Arslan H, Ertas ET. Comparative study of different novel nickel-titanium rotary systems for root canal preparation in severely curved root canals. J Endod 2014;40:852–856.
13. Gutmann JL. Problem solving in endodontics: prevention, identification, and management, 5th ed. St Louis: Mosby, 2011.
14. Salzgeber RM, Brilliant JD. An in vivo evaluation of the penetration of an irrigating solution in root canals. J Endod 1977;3:394–398.
15. Druttman AC, Stock CJ. An in vitro comparison of ultrasonic and conventional methods of irrigant replacement. Int Endod J 1989;22:174–178.
16. Torabinejad M, Handysides R, Khademi A, Bakland LK. Clinical implications of the smear layer in endodontics: a review. Oral Surg Oral Med Oral Pathol Ora Radiol Endod 2002;94:658–666.
17. De Moor RJ, Meire M, Goharkhay K, Moritz A, Vanobbergen J. Efficacy of ultrasonic versus laser-activated irrigation to remove artificially placed dentin debris plugs. J Endod 2010;36:1580–1583.
18. Xavier F, Nevares G, Romeiro MK, Gonçalves K, Gominho L, Albuquerque D. Apical extrusion of debris from root canals using reciprocating files associated with two irrigation systems. Int Endod J, in press, doi: 10.1111/iej.12362.
19. Karatas E, Ozsu D, Arslan H, Erdogan AS. Comparison of the effect of nonactivated self-adjusting file system, Vibringe, EndoVac, ultrasonic and needle irrigation on apical extrusion of debris. Int Endod J 2015;48:317–322.

20. Myers GL, Montgomery S. A comparison of weights of debris extruded apically by conventional filing and Canal Master techniques. J Endod 1991;17:275–279.
21. al-Omari MA, Dummer PM. Canal blockage and debris extrusion with eight preparation techniques. J Endod 1995;21: 154–158.
22. Bürklein S, Hinschitza K, Dammaschke T, Schäfer E. Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne versus Mtwo and ProTaper. Int Endod J 2012;45:449–461.
23. Ruddle CJ, Machtou P, West JD. The shaping movement: fifth-generation technology. Dent Today 2013;32:96–99.
24. De-Deus G, Barino B, Zamolyi RQ, et al. Suboptimal debridement quality produced by the single-file F2 ProTaper technique in oval-shaped canals. J Endod 2010;36:1897–1900.
25. Bürklein S, Schäfer E. Apically extruded debris with reciprocating single-file and full-sequence rotary instrumentation systems. J Endod 2012;38:850–852.
26. 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;5:405–409.
27. 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;19:357–361.
28. Kirchhoff AL, Fariniuk LF, Mello I. Apical extrusion of debris in flat-oval root canals after using different instrumentation systems. J Endod 2014;41:237–241.
29. Gambarini G, Testarelli L, De Luca M, et al. The influence of three different instrumentation techniques on the incidence of postoperative pain after endodontic treatment. Ann Stomatol (Roma) 2013;4:152–155.
30. Boutsioukis C, Lambrianidis T, Verhaagen B, et al. The effect of needle-insertion depth on the irrigant flow in the root canal: evaluation using an unsteady computational fluid dynamics model. J Endod 2010;36:1664–1668.
31. DiVito E, Olivi G. Review: Photoacoustic endodontics using PIPS^{TM}: experimental background and clinical protocol. J LA&HA 2012;1:22–25.
32. De Moor RJ, Blanken J, Meire M, Verdaasdonk R. Laser induced explosive vapor and cavitation resulting in effective irrigation of the root canal. Part 2: evaluation of the efficacy. Lasers Surg Med 2009;41:520–523.
33. Peeters HH, Suardita K. Efficacy of smear layer removal at the root tip by using ethylenediaminetetraacetic acid and erbium, chromium: yttrium, scandium, gallium garnet laser. J Endod 2011;37:1585–1589.
34. Arslan H, Akcay M, Capar ID, et al. Efficacy of needle irrigation, EndoActivator, and photon-initiated photoacoustic streaming technique on removal of double and triple antibiotic pastes. J Endod 2014;40:1439–1442.
35. Arslan H, Capar ID, Saygili G, Gok T, Akcay M. Effect of photon-initiated photoacoustic streaming on removal of apically placed dentinal debris. Int Endod J 2014;47:1072–1077.
36. Hmud R, Kahler WA, George R, Walsh LJ. Cavitational effects in aqueous endodontic irrigants generated by near-infrared lasers. J Endod 2010;36:275–278.
37. Mir M, Gutknecht N, Poprawe R, Vanweersch L, Lampert F. Visualising the procedures in the influence of water on the ablation of dental hard tissue with erbium:yttriumaluminium-garnet and erbium, chromium:yttrium-scandium-gallium-garnet laser pulses. Lasers Med Sci 2009;24:365–374.
38. Peeters HH, De Moor RJ. Measurement of pressure changes during laser-activated irrigant by an erbium, chromium: yttrium, scandium, gallium, garnet laser. Lasers Med Sci 2014 [Epub ahead of print].
39. Peeters HH, Mooduto L. Radiographic examination of apical extrusion of root canal irrigants during cavitation induced by Er, Cr:YSGG laser irradiation: an *in vivo* study. Clin Oral Investig 2013;17:2105–2112.

Address correspondence to:
Kürşat Er
Department of Endodontics
Faculty of Dentistry
Akdeniz University
Antalya
Turkey

E-mail: qursater@hotmail.com