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

Flávio R.F. Alves, PhD, Marília F. Marceliano-Alves, PhD,* Júlio Cézar N. Sousa, MSc,*† Stephanie B. Silveira, MSc,* José C. Provenzano, PhD,* and José F. Siqueira, Jr, PhD**

Abstract

Introduction: This study compared the efficacy of a reciprocating single-instrument system and a rotary multi-instrument system followed by a supplementary approach with a finishing instrument in removing the filling material from curved canals during retreatment. **Methods:** Forty mesial canals from extracted mandibular molars were instrumented and filled. Then, each mesial canal was retreated by using either Reciproc (VDW, Munich, Germany) or Mtwo (VDW) instruments, alternating the technique used per canal from root to root. The working time was recorded, and the percentage of removed filling volume was assessed by means of micro–computed tomography imaging before and after retreatment. Canals still showing filling material remnants were subjected to an adjunctive approach with the XP-Endo Finisher (FKG Dentaire, La Chaux-de-Fonds, Switzerland), and another microCT scan was taken. Data were statistically analyzed with a significance level of 5%. **Results:** The percentage of filling material removed with Mtwo instruments (96%) was significantly higher than Reciproc (89%) ($P < .05$), both used up to a final instrument size of 40. Mtwo required less time to remove the filling material than Reciproc ($P < .05$). Intragroup analysis in the Reciproc group showed that the R40 instrument removed significantly more filling material than R25 ($P < .05$). The supplementary approach with the XP-Endo Finisher was effective in significantly enhancing the removal of filling material ($P < .05$). **Conclusions:** The rotary multiple-instrument system was more effective and faster than the reciprocating single-instrument approach in removing previous root canal fillings. As for the Reciproc group, it was observed that the larger instrument promoted significantly better results. The adjunctive finishing instrument XP-Endo Finisher significantly improved filling material removal. *(J Endod 2016;42:1114–1119)*

Key Words

Endodontic retreatment, reciprocating single-file system, root canal preparation, rotary instruments

Significance

Using a highly accurate evaluation method, this study showed that a rotary multi-instrument system (Mtwo) was more effective and faster than a reciprocating single-instrument system (Reciproc) in removing the filling material from curved canals during retreatment. Additionally, a supplementary approach with the XP-Endo Finisher enhanced filling removal.

Root canal retreatment usually represents a significant technical challenge for clinicians, especially in teeth with well-filled curved canals (1). The resistance imposed by the compacted filling material makes removal difficult with increased risks of accidents. Failure in completely removing the previous filling material can make proper disinfection difficult by restricting the access of antimicrobial agents to certain areas of the root canal system (2). Filling remnants may cover areas in which residual infection occurs. If bacteria remain in the apical canal, there is an increased risk for maintaining periradicular inflammation (3).

Different techniques have been proposed to remove filling materials, most of the recent ones using nickel-titanium (NiTi) rotary instruments. Some systems are specially designed for use in retreatment, including the Mtwo Retreatment instruments (VDW, Munich, Germany). This system comprises 2 instruments (R1 [15/0.05] and R2 [25/0.05]) that have a cutting tip in order to facilitate penetration into the filling mass. After the retreatment instrument removes the gross part of the filling material, the canal is prepared with the system of preference. Alternatively, some authors have proposed removing the previous filling material with reciprocating single-instrument systems originally designed for root canal preparation (4–11). In this case, filling removal is performed simultaneously with reinstrumentation. One of the most popular single-instrument systems used for this purpose is Reciproc (VDW). Three instrument sizes are available: 25/0.08 mm for narrow canals, 40/0.06 mm for

From the *Department of Endodontics, Faculty of Dentistry, Estácio de Sá University, Rio de Janeiro, Rio de Janeiro, Brazil; and †Department of Endodontics, Faculty of Dentistry, University Center of João Pessoa, Paraíba, Brazil.

Address requests for reprints to Flávio R.F. Alves, Faculty of Dentistry, Estácio de Sá University, Av Alfredo Baltazar da Silveira, 580/cobertura, Recreio, Rio de Janeiro, RJ 22790-710, Brazil. E-mail address: flavioferreiraalves@gmail.com

0099-2399/$ - see front matter

http://dx.doi.org/10.1016/j.joen.2016.04.007

medium-volume canals, and 50/0.05 mm for large canals. The Reciproc instrument has the same cross-sectional design (2-fluted file with "S" shape) as the Mtwo instruments from the same manufacturer but with an opposed cutting direction of the flutes.

Irrespective of the retreatment technique, numerous studies have shown that complete removal of root canals fillings is not commonly attained (9, 10, 12–16), particularly in the apical portion of the root canal (14, 17, 18). Therefore, additional approaches have been suggested to enhance the removal of filling material (15, 18, 19). Recently, a new NiTi finishing instrument was developed with the purpose of improving root canal cleaning—the XP-Endo Finisher (FKG Dentaire, La Chaux-de-Fonds, Switzerland), which is a size 25 nontapered instrument made with the NiTi MaxWire alloy (Martensite-Austenite ElectropolishFleX, FKG Dentaire). Because of this special alloy, this instrument is straight in its martensitic phase, which is achieved below 30°C; however, when placed in the canal at the body temperature, it changes to the austenitic phase in which the instrument assumes a spoon shape in the last 10 mm with a depth of approximately 1.5 mm. When rotating, this instrument achieves a natural diameter of 3 mm in the last 10 mm (Fig. 1). According to the manufacturer, when the instrument tip is squeezed, the bulb can be expanded to 6 mm; when the bulb is compressed, the tip will expand to 6 mm. Thus, when the XP-Endo instrument is moved up and down for 7 to 8 mm inside the canal, the natural constrictions and expansions in the canal will alternately cause the bulb and tip to expand and contract. This makes the instrument scrape the canal walls and cause turbulence of the irrigant solution. It seems that the XP-Endo Finisher instrument has the potential to be applied as an additional procedure in retreatment cases to maximize filling removal.

As for removal of the root canal filling material in curved canals, the following questions remain unanswered: What instrumentation system is more effective for filling removal in curved canals? Do reciprocating single-instrument systems perform similarly to rotary multi-instrument systems? and Can supplementary approaches enhance filling removal? Few studies addressed these questions using a 3-dimensional high-accuracy method like micro–computed tomographic (microCT) imaging. In 1 study, the ProTaper Universal Retreatment system (Dentsply Maillefer, Ballaigues, Switzerland) was compared with Reciproc and Hedström files, and no significant differences were found between groups (9). However, in a study using flattened canals, Reciproc was associated with less remaining material when compared with ProTaper and Hedström files; a supplementary step with passive ultrasonic irrigation (PUI) significantly reduced the amount of residual material in all groups (20). Another study compared Reciproc with WaveOne (Dentsply Maillefer) systems before and after PUI with xylene and observed no statistical significant differences between the 2 instrumentation techniques; no significant reduction in residual material was promoted by the supplementary step of PUI with xylene either (11).

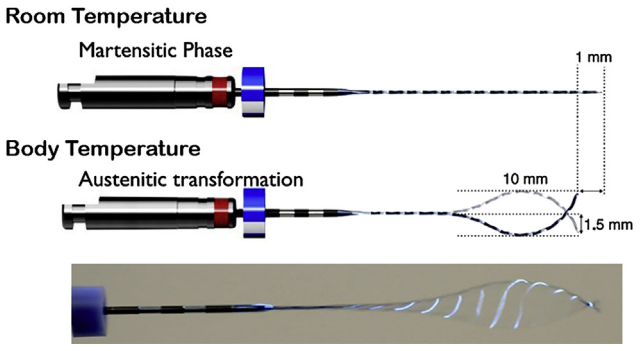

Figure 1. Mechanism of action of the XP-Endo Finisher instrument.

The purpose of the present study was 3-fold:

1. To compare the efficacy of a reciprocating single-instrument system (Reciproc) with a rotary multi-instrument system (Mtwo) both using instruments with a similar cross-sectional design
2. To compare the effects of using 2 instrument sizes of the Reciproc system (R25 and R40) on filling removal
3. To evaluate the additional cleaning effects of a new instrument (XP-endo Finisher) as an adjunctive approach

For these analyses, the microCT technology was used.

Materials and Methods

Specimen Selection and Initial Preparation

The study protocol was approved by the Ethics Committee of the University Center of João Pessoa, João Pessoa, PB, Brazil. The mandibular molars used were selected from a collection of 165 molars extracted for reasons not related to this study and pertaining to the institutional human tooth bank. Teeth with mesial root curvatures between 30° and 40° were initially radiographed both in the buccolingual and mesiodistal directions to check for the presence of 2 distinct mesial canals. Next, they were decoronated at the level of the cementodentinal junction, and the mesial roots were separated with the aid of a diamond disc (Brasseler, Savannah, GA). All roots were carefully inspected under an operative microscope with 5× magnification in order to verify the apexes were completely formed and the root surfaces were free from evident cracks or resorption. The root canals were explored with a size 10 K-type file (Dentsply Maillefer) until the instrument tip was visible at the apical foramen under magnification. This procedure was performed to measure the length of both mesial canals, check for the presence of 2 independent foramina, and confirm their patency. Finally, radiographs were once again taken with the files within the canals to confirm the occurrence of 2 independent canals. Therefore, only roots classified as Vertucci's type IV were included in the study. Twenty roots were selected according to these criteria.

Preparation of both mesial canals was performed with Mtwo instruments in the following sequence: 10/0.04, 15/0.05, 20/0.06, and 25/0.06. The instruments were used in continuous rotation powered by the VDW Silver motor in the Mtwo mode. The working length (WL) was established 1 mm short of the apical foramen. The canals were copiously irrigated with 2.5% sodium hypochlorite (NaOCl) and checked for apical patency with a size 15 K-type file throughout the instrumentation procedures. Irrigation was performed using 30-G NaviTip needles (Ultradent, South Jordan, UT) taken up to 3 mm short of the WL. After preparation was complete, the smear layer was removed by rinsing the canals with 2 mL 17% EDTA for 3 minutes followed by 2 mL 2.5% NaOCl. Afterward, the canals were dried with absorbent paper points and subsequently filled with the single-cone technique using Mtwo 25/0.06 gutta-percha points (VDW) combined with Sealer 26 (Dentsply, Petrópolis, RJ, Brazil). The coronal cavity was sealed with Coltosol (Vigodent, Rio de Janeiro, RJ, Brazil), and the quality of canal fillings was checked by buccolingual and mesiodistal radiographic projections. If voids were detected, the tooth was discarded and replaced. The specimens were stored in 100% humidity at 37°C for 14 days to allow the sealer to set.

Initial microCT Imaging Analysis

The specimens were scanned in an 800-μA SkyScan 1174v2 microCT scanner (Bruker-microCT, Kontich, Belgium) with a 50-kV X-ray source. The parameters used for scanning included a rotation

step of 1°, 360° rotation around the vertical axis, 19.9-μm isotropic resolution, and a 0.5-mm-thick aluminum filter. The image of each specimen was reconstructed using NRecon v.1.6.9 software (Bruker-microCT), which provided axial and transverse slices of the internal structure. The initial volumes of the filling material were quantified in all root canals using CTAN v1.5.4.0 (Bruker-microCT). Quantitative 3-dimensional evaluation of the root canal filling volume was obtained using the plug-in 3-dimensional analysis tool. For standardization, analyses of volume were restricted to the apical 5 mm of filling mass.

Retreatment Procedures

Retreatment procedures were performed by removing the previous filling material from each canal using either Mtwo or Reciproc. Both systems were used in the same root but alternating the mesial canals from root to root. Therefore, 20 root canals were included per group (10 mesiobuccal and 10 mesiolingual canals). This procedure permitted a better control of variables related to the anatomy. The filling material in the most coronal segment of the canal was removed using Gates-Glidden burs size 2 taken up to 3 mm apical to the canal opening, and the root canals were prepared as follows.

The Mtwo Group. The main bulk of filling material was removed by using the Mtwo Retreatment instruments 15/0.05 and 25/0.05 up to two thirds of the canal length. Patency of the apical foramen was checked with a size 15 K-type hand file, and the canal was irrigated with 2 mL 2.5% NaOCl for 30 seconds. The canal was then prepared by using the following sequence of Mtwo instruments in a brushing motion at the WL: 20/0.06, 25/0.06, 30/0.05, 35/0.04, and 40/0.04. The root canals were irrigated after each instrument size using 2 mL 2.5% NaOCl for 30 seconds and then after the last instrument of the sequence. Each Mtwo instrument was used to prepare 4 canals.

The Reciproc Group. The Reciproc instrument R25 was moved in the apical direction in a reciprocating motion using in-and-out pecking motions of 3 mm in amplitude. The progression was performed with light apical pressure until the instrument reached two thirds of the canal length. After 3 pecking motions, the instrument was removed and cleaned, and the canal was irrigated with 4 mL NaOCl for 60 seconds. Another cycle of 3 pecking motions was performed until the R25 instrument reached the WL. The instrument was then used in a brushing motion, and the canal was irrigated with 4 mL NaOCl for 60 seconds. Patency of the apical foramen was checked with a size 15 K-type file. In the Reciproc group, the efficacy of filling material removal was also compared between instruments R25 and R40. Therefore, at this time, the roots were subjected to another microCT scan using the same parameters as described previously. Then, the Reciproc R40 instrument was used up to the WL with a brushing motion against the lateral walls. Finally, the canal was irrigated with 4 mL NaOCl for 60 seconds. Each Reciproc instrument was used to prepare one canal.

In both groups, complete removal of the filling material was considered when the canal walls were regarded as smooth and no remaining filling material was observed on the instrument flutes. Irrigation during preparation was always performed with 30-G NaviTip needles taken up to 3 mm short of the WL. The total volume of NaOCl irrigation was identical for both groups (12 mL). The time of the intracanal procedures elapsed from the initial filling removal with the Gates-Glidden bur until the final irrigation with NaOCl was recorded. The time spent for instrument changes, radiographs, and microCT imaging was not included.

Postpreparation microCT Imaging Analysis

After retreatment procedures with both systems, the roots were scanned again in the microCT device with the same parameters outlined previously. The remaining volumes of filling material were quantified in all root canals using CTAn software (Bruker-microCT).

Supplementary Cleaning Approach

An additional approach with the XP-Endo Finisher instrument was performed in the root canals that presented with remaining filling materials as detected in postpreparation microCT imaging. The root canal was irrigated with 2 mL 2.5% NaOCl warmed at 37°C for 30 seconds. The XP-Endo Finisher was operated in the canal for 1 minute at 1000 rpm and 1 Ncm up to the WL and in slow up and down 7- to 8-mm long movements. Parietal movements were applied during the procedure. Finally, the root canal was irrigated with the same volume of warmed 2.5% NaOCl for 30 seconds. All procedures with the XP-endo Finisher were performed at 37°C inside a cabinet containing a heater (800-Heater; PlasLabs, Lansing, MI).

Final microCT Imaging Analysis

After using the XP-Endo Finisher, the roots were once again scanned in the microCT device using the same parameters as described earlier and evaluated for remnants of filling material.

Statistical Analysis

Initially, the Kolmogorov-Smirnov test was applied to test for data normality. The Mann-Whitney test was used to assess whether the initial volumes of filling material differed significantly in both groups and to compare the percentage of filling material removed by the 2 techniques (intergroup analysis). The Wilcoxon matched pairs test was used to compare the percentage of gutta-percha removed with the Reciproc R25 and R40 instruments (intragroup analysis). The difference in the working time between groups was analyzed by the Student *t* test. Finally, the efficacy of the supplementary step with the XP-Endo Finisher was evaluated by the Student *t* test using data from the filling material volumes before and after this procedure. The level of significance was set at 5% for all statistical tests ($P < .05$).

Results

The mean volume of material before retreatment was 1.03 mm^3 in the MTwo group and 1.05 mm^3 in the Reciproc group. There was no significant difference in these initial filling material volumes between groups ($P > .05$). The mean percent filling material removal was 96% (range, 48.6%–100%) for the Mtwo group and 89.4% (range, 55.6%–100%) for Reciproc R40. The approach using the MTwo instruments promoted a significantly larger removal of filling material when compared with Reciproc R40 ($P < .05$) (Fig. 2*A–C* and Table 1). Regarding the total time of preparation, Mtwo instruments required less time to remove the filling material than Reciproc R40 ($P < .01$) (Table 2). Intragroup analysis in the Reciproc group revealed significantly higher filling material removal using R40 compared with R25 ($P < .01$).

The XP-Endo Finisher was used in 17 canals with residual filling material as determined by microCT imaging (12 in the Reciproc group and 5 in the Mtwo group). The mean volume of material remnants in these canals before application of the XP-Endo Finisher was 0.15 mm^3. The XP-Endo Finisher resulted in a mean 69% reduction of the residual filling material volume; this was statistically significant ($P < .05$) (Fig. 2). Fourteen canals still showed a small amount of filling material after using the XP-Endo Finisher (mean 0.06 mm^3).

Discussion

The present study evaluated the efficacy of 2 instrument systems supplemented or not by a new finishing instrument in removing the

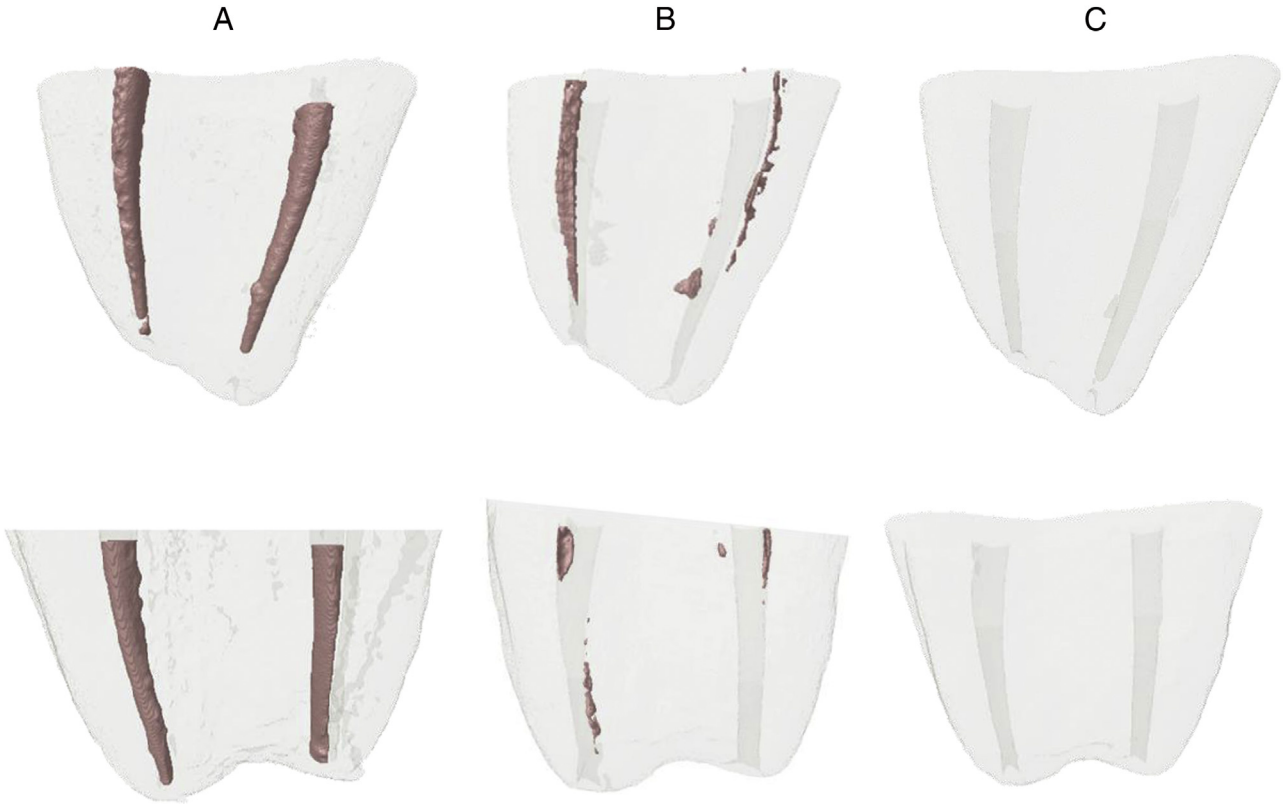

Figure 2. MicroCT images of representative specimens subjected to retreatment procedures. Only the apical segment of roots was reconstructed. (*A*) The initial microCT scan taken after root canal filling. (*B*) A postpreparation microCT scan taken after retreatment procedures with both systems: left canals with Reciproc and right canals with Mtwo. (*C*) The final microCT scan after using the XP-Endo Finisher.

previous filling material for retreatment. These analyses were performed using the mesial roots of mandibular molars, which have been shown to exhibit a complex anatomy and the common presence of curvature (21, 22). These anatomic features pose a challenge for retreatment and provided the basis for selecting these teeth for the study. To minimize variables inherent to anatomy, both systems were evaluated in the same root, alternating the mesial canals from specimen to specimen, allowing the comparison of the 2 techniques in similar anatomic conditions. Moreover, for standardization, groups were compared for the ability to remove the apical 5 mm of the root canal filling mass. As a consequence of these controlled conditions, the initial volume occupied by the root canal filling material in both groups was statistically similar and allowed for reliable intergroup comparisons to be made.

Previous studies showed controversial results regarding filling material removal using Reciproc instruments in comparison with multi-instrument retreatment techniques. Two studies showed better results for Reciproc compared with Mtwo (8) or ProTaper Universal Retreatment (20). In the former study, maxillary central incisors were subjected to retreatment procedures, and analysis was performed on the basis of photographs taken after splitting the teeth (8). The latter study was a microCT evaluation using mandibular incisors (20). Both studies adopted #50 as the final instrument size. However, 2 studies found no significant differences between Reciproc and the ProTaper Universal Retreatment system (9, 10). One of them used curved canals retreated to a final instrument size of 40 using microCT analysis (9). The percentage of filling material removal with Reciproc was 91.7% in a previous study (9) and was close to the figure observed in the present investigation (89.4%). As for the multi-instrument techniques, similar results also occurred for different techniques (93.6% in the study using the ProTaper Universal Retreatment system [9] and 96% in the present one using Mtwo). Reciproc and the MTwo systems were chosen because they are similar in design, therefore permitting a well-controlled comparison between a reciprocating single-instrument system and a continuously rotating multi-instrument system.

Although similar in design, it was not possible to standardize the tapers because Reciproc has a variable taper along the shaft. Because the tip sizes were the same, it was expected that Reciproc would

TABLE 1. Volume of Filling Material in the Apical Portion of Mesial Canals of Mandibular Molars before and after Using Mtwo or Reciproc Instruments for Retreatment

Group	*n*	Mean volume before (±SD)*	Mean volume after (±SD)*	Mean % reduction (median)	Range % reduction
Mtwo	20	1.03 (0.32)	0.03 (0.05)	96 (100)	48.6–100
Reciproc R25	20	1.05 (0.31)	0.31 (0.32)	69.8 (80.9)	6.7–100
Reciproc R40	20	1.05 (0.31)	0.10 (0.14)	89.4 (96.3)	55.6–100

SD, standard deviation.

*Values in mm^3.

TABLE 2. Total Working Time for Retreatment in Mesial Canals of Mandibular Molars with Either Mtwo or Reciproc Instruments (in minutes)

Group	*n*	Mean (±SD)	Minimum	Maximum
Mtwo	20	4.46 (1.18)	2.78	6.47
Reciproc R40	20	5.45 (0.89)	3.38	6.58

SD, standard deviation.

promote larger filling material removal. However, the results indicated the opposite. A plausible explanation for the better performance of the Mtwo system seems to be related to the continuous rotation movement, which may produce a constant flow of debris in the coronal direction. In the reciprocating movement, there is a trend for debris to be displaced apically rather than moved coronally (23) although this remains controversial (24). Probably, in standardized conditions of irrigation, the effects of the movement type may have overcome the small differences in taper. Also, the better results may be related to the previous use of MTwo Retreatment instruments, which are designed to remove gutta-percha fillings, or the fact that using several instruments in the multiple-instrument approach may have increased the chances for residual material to be removed. Further studies are necessary to confirm these assertions.

With respect to speed, the Mtwo technique was faster than Reciproc, which is curious considering that this is against the expectation for a single-instrument technique. To understand this result, it is important to consider some aspects of Reciproc in comparison with the Mtwo Retreatment system. First, the Reciproc system was originally developed for root canal preparation and later proposed and adapted for retreatment. The tip design is noncutting, and the transition between the tip and the helical shaft is a curve (25). Mtwo Retreatment instruments (R15 and R25) were specifically designed for retreatment, and the transition between the tip and the helical shaft is an angle that provides a good cutting ability (26). Finally, the movement applied could have influenced the speed of instrument advance in the filled canal. The rotary motion applied to Mtwo files produces a screwing effect that may facilitate a rapid instrument penetration; this may not occur during the reciprocating motion. A previous study found opposite results using both systems in straight canals (8). The use of solvent in that previous study may have helped to overcome the difficulty of apical advance with Reciproc. In addition to the different tooth type and procedures used, it is important to point out that the operator may also influence the working time and contribute to differences.

Different from many other studies (8–10, 20, 27), the retreatment protocols used removed 100% of the filling material in more than half of the cases (15 canals from the Mtwo group and 8 canals from the Reciproc group [R40]). Possible explanations for this difference in comparison with previous studies is that the present one used independent mesial canals with cross sections that were almost circular, and evaluation was restricted to the apical portion. The significantly lower amount of residual filling material after using Reciproc R40 compared with R25 indicates that the size of apical instrumentation significantly influences removal of the previous filling material for retreatment, as expected.

The volume of residual filling material after using size 40 instruments was minimal. Although the real impact of the amount of filling material remnants in the endodontic retreatment outcome is unknown, studies using histologic evaluation of teeth with post-treatment apical periodontitis disclosed some cases in which bacteria may have remained sheltered by the filling material (28–30). Thus, it is reasonable to assume that remnants of filling material may compromise the outcome of retreatment in teeth with apical periodontitis, and efforts should be directed toward improving cleanliness.

A new supplementary strategy using a finishing instrument was evaluated for its ability to improve filling material removal. The results using the XP-Endo Finisher instrument were encouraging because the remaining filling volume was significantly reduced after its use. The instrument expansion at the body temperature added to its helical movement inside the canal may have allowed it to touch and displace the residual filling material. PUI is another supplementary strategy that may be used to improve cleaning during retreatment; however, previous studies have shown conflicting results after using PUI in retreatment (11, 20).

In conclusion, the Mtwo retreatment technique was more effective and faster than Reciproc in removing filling material from curved canals. Reciproc R40 removed significantly more material than Reciproc R25. In canals still exhibiting filling remnants, an adjunctive approach with the XP-Endo Finisher instrument significantly enhanced removal.

Acknowledgments

Supported by grants from the Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ), a Brazilian Governmental Institution.

The authors deny any conflicts of interest related to this study.

References

1. Schirrmeister JF, Wrbas KT, Schneider FH, et al. Effectiveness of a hand file and three nickel-titanium rotary instruments for removing gutta-percha in curved root canals during retreatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:542–7.
2. Siqueira JF Jr. *Treatment of Endodontic Infections*. London: Quintessence Publishing; 2011.
3. Ricucci D, Siqueira JF Jr, Bate AL, Pitt Ford TR. Histologic investigation of root canal-treated teeth with apical periodontitis: a retrospective study from twenty-four patients. J Endod 2009;35:493–502.
4. de Souza PF, Oliveira Goncalves LC, Franco Marques AA, et al. Root canal retreatment using reciprocating and continuous rotary nickel-titanium instruments. Eur J Dent 2015;9:234–9.
5. Silva EJ, Sa L, Belladonna FG, et al. Reciprocating versus rotary systems for root filling removal: assessment of the apically extruded material. J Endod 2014;40:2077–80.
6. Barletta FB, Rahde Nde M, Limongi O, et al. *In vitro* comparative analysis of 2 mechanical techniques for removing gutta-percha during retreatment. J Can Dent Assoc 2007;73:65.
7. Martinho FC, Freitas LF, Nascimento GG, et al. Endodontic retreatment: clinical comparison of reciprocating systems versus rotary system in disinfecting root canals. Clin Oral Investig 2015;19:1411–7.
8. Zuolo AS, Mello JE Jr, Cunha RS, et al. Efficacy of reciprocating and rotary techniques for removing filling material during root canal retreatment. Int Endod J 2013;46:947–53.
9. Rodig T, Reicherts P, Konietschke F, et al. Efficacy of reciprocating and rotary NiTi instruments for retreatment of curved root canals assessed by micro-CT. Int Endod J 2014;47:942–8.
10. Rios Mde A, Villela AM, Cunha RS, et al. Efficacy of 2 reciprocating systems compared with a rotary retreatment system for gutta-percha removal. J Endod 2014;40:543–6.
11. Fruchi LC, Ordinola-Zapata R, Cavenago BC, et al. Efficacy of reciprocating instruments for removing filling material in curved canals obturated with a single-cone technique: a micro-computed tomographic analysis. J Endod 2014;40:1000–4.
12. Bramante CM, Fidelis NS, Assumpcao TS, et al. Heat release, time required, and cleaning ability of MTwo R and ProTaper universal retreatment systems in the removal of filling material. J Endod 2010;36:1870–3.
13. Tasdemir T, Er K, Yildirim T, Celik D. Efficacy of three rotary NiTi instruments in removing gutta-percha from root canals. Int Endod J 2008;41:191–6.
14. So MV, Saran C, Magro ML, et al. Efficacy of ProTaper retreatment system in root canals filled with gutta-percha and two endodontic sealers. J Endod 2008;34:1223–5.
15. Hammad M, Qualtrough A, Silikas N. Three-dimensional evaluation of effectiveness of hand and rotary instrumentation for retreatment of canals filled with different materials. J Endod 2008;34:1370–3.
16. Silva EJ, Orlowsky NB, Herrera DR, et al. Effectiveness of rotatory and reciprocating movements in root canal filling material removal. Braz Oral Res 2015;29:1–6.
17. Alves FR, Ribeiro TO, Moreno JO, Lopes HP. Comparison of the efficacy of nickel-titanium rotary systems with or without the retreatment instruments in the removal of gutta-percha in the apical third. BMC Oral Health 2014;14:102.

18. Alves FR, Vieira MV, Moreno JO, et al. Removal of filling material in the apical root canal by three retreatment approaches. ENDO (Lond Engl) 2012;6:257–62.
19. Farge P, Nahas P, Bonin P. *In vitro* study of a Nd:YAP laser in endodontic retreatment. J Endod 1998;24:359–63.
20. Bernardes RA, Duarte MA, Vivan RR, et al. Comparison of three retreatment techniques with ultrasonic activation in flattened canals using micro-computed tomography and scanning electron microscopy. Int Endod J 2015 Aug 17 [Epub ahead of print].
21. de Pablo OV, Estevez R, Peix Sanchez M, et al. Root anatomy and canal configuration of the permanent mandibular first molar: a systematic review. J Endod 2010;36:1919–31.
22. Kartal N, Cimilli HK. The degrees and configurations of mesial canal curvatures of mandibular first molars. J Endod 1997;23:358–62.
23. Burklein S, Benten S, Schafer 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.
24. 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.
25. Caballero H, Rivera F, Salas H. Scanning electron microscopy of superficial defects in Twisted files and Reciproc nickel-titanium files after use in extracted molars. Int Endod J 2015;48:229–35.
26. Hussne RP, Braga LC, Berbert FL, et al. Flexibility and torsional resistance of three nickel-titanium retreatment instrument systems. Int Endod J 2011;44:731–8.
27. Rodig T, Hausdorfer T, Konietschke F, et al. Efficacy of D-RaCe and ProTaper Universal Retreatment NiTi instruments and hand files in removing gutta-percha from curved root canals - a micro-computed tomography study. Int Endod J 2012;45:580–9.
28. Ricucci D, Siqueira JF Jr. Fate of the tissue in lateral canals and apical ramifications in response to pathologic conditions and treatment procedures. J Endod 2010;36:1–15.
29. Vieira AR, Siqueira JF Jr, Ricucci D, Lopes WS. Dentinal tubule infection as the cause of recurrent disease and late endodontic treatment failure: a case report. J Endod 2012;38:250–4.
30. Vera J, Siqueira JF Jr, Ricucci D, et al. One- versus two-visit endodontic treatment of teeth with apical periodontitis: a histobacteriologic study. J Endod 2012;38:1040–52.