

Self-Adjusting Files in Retreatment: A High-resolution Micro-Computed Tomography Study

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Abstract

Introduction: Rotary instruments that are used for retreatment are very effective, but most of them leave root filling residue in the canal. The aim of this study was to evaluate the efficacy of removing gutta-percha-based root fillings with ProTaper retreatment files (Dentsply Maillefer, Ballaigues, Switzerland) followed by F1 and F2 ProTaper instruments and to compare these results with those obtained with a #25 .06 ProFile instrument (Dentsply Maillefer) followed by the Self-Adjusting File (SAF; ReDent, Ra'anana, Israel) using high resolution micro-computed tomography (CT) scanning.

Methods: Twenty-eight mandibular molar teeth with oval distal root canals were divided into 2 equal groups of 14 teeth each. The distal root canals were instrumented with ProTaper files up to an F2 instrument, the roots were subsequently filled, and the root filling was allowed to set fully. Removal of the root canal filling was performed with D1-D3 ProTaper retreatment files followed by F1 and F2 ProTaper instruments or with a #25 .06 ProFile followed by SAFs. Chloroform was used in both groups to assist in the removal of the root filling material. High-resolution micro-CT scans were used to measure the residual quantities of the root filling material after completion of the procedures. Statistical analysis was performed using the Wilcoxon test and the Student *t* test. **Results:** The median root filling residue in the ProTaper group was 5.39% (interquartile range [IQR] = 4.71) of the original volume of the root canal filling. In the ProFile and SAF group, the median residue was 0.41% (IQR = 1.64, *P* < .001). An arbitrarily selected threshold of less than 0.5% residue was defined as "effectively cleaned," and 57% of the teeth treated with the ProFile and the SAF met this threshold, whereas none of the cases in the ProTaper group did. The ProFile and SAF procedure required less time than the ProTaper protocol. **Conclusions:** None of the retreatment methods rendered all of the canals completely free of all root filling residue. Under the conditions of this study, the ProFile and SAF procedure

was more effective than the ProTaper procedure and left significantly less root filling residue in the root canal. (*J Endod* 2012;38:1283–1287)

Key Words

Micro-CT, ProTaper, retreatment, Self-Adjusting File

The initial stage of any retreatment procedure is the removal of previous root filling material to allow adequate cleaning, disinfection, and obturation of the root canal space (1, 2). This task can easily be accomplished with rotary files, which allow the removal of the bulk of gutta-percha-based root filling material within a few minutes (3–9). However, recent studies have indicated that such a procedure performed on its own leaves a significant amount of root filling residue along the canal wall (4, 10–12). This finding may partly explain the low reported success rate of retreatment in cases with posttreatment disease (13).

In straight canals, an operating microscope can be used to evaluate and facilitate the removal of root filling residues. In contrast, curved canals limit the view beyond the curvature, and the operator has to rely on radiographs (12), which have recently been shown to be unreliable and misleading for such evaluations (7, 11).

Recently, Abramovitz et al (12) tested the efficacy of the Self-Adjusting File (SAF) system (ReDent, Ra'anana, Israel) in removing root filling residue that had been left in curved canals after using ProTaper retreatment files (Dentsply Maillefer, Ballaigues, Switzerland). After the removal of the bulk of the filling material, a drop of chloroform was placed in the canal, and the SAF was used for 1 minute without irrigation followed by 3 minutes with sodium hypochlorite irrigation, resulting in much cleaner canals than when only rotary files were used.

The present study extended these observations to include oval canals in the distal roots of mandibular molars. Rotary instruments may effectively remove root fillings from straight, narrow canals with round cross-sections. However, for oval canals, rotary instruments are likely to be less effective as indicated by their inability to shape oval canals (14). We assumed that because the SAF is supposed to adapt to the cross-section of oval canals and exert a scrubbing effect on the canal walls (15, 16), the SAF may also perform well during retreatment under these challenging conditions.

In the aforementioned study (12), planar 2-dimensional (2D) radiographs were used to evaluate the results. Recent studies have shown the limitations of 2D radiographs for these types of evaluations (7, 11); therefore, we used a high-resolution micro-computed tomography (CT) scan instead. It has recently been shown that this method can easily be adapted to differentiate between canal walls and root filling material (17). Additionally, this method enables 3-dimensional (3D) evaluation of the entire canal and avoids any potential operator bias during the interpretation of the

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results. The present study was designed to evaluate the efficacy of removing root fillings with ProTaper retreatment files followed by F1 and F2 ProTaper instruments and to compare these results with those obtained with a #25 .06 ProFile instrument (Dentsply Maillefer) followed by the SAF using high-resolution micro-CT scans.

Materials and Methods

Selection of Teeth

Forty mandibular molars were selected from a random collection of teeth that had been extracted for periodontal reasons. Initial inclusion criteria were a single distal root canal, no previous root canal treatment, straight roots of similar length, and completely developed apices. Specimens were subsequently mounted on scanning electron microscopy carriers (014001-T; Bal-Tec AG, Balzers, Liechtenstein) and pre-scanned using a high-resolution micro-CT system (μ CT 40; Scanco Medical, Brüttisellen, Switzerland) with an isotropic resolution of 20 μ m at settings of 70 kV and 114 μ A. Based on the root canal cross-sections of the initial scans, the teeth were divided into 2 groups using the flatness of the canal as the key parameter. The ratio of the buccolingual to the mesiodistal diameter of the canal was calculated 6 mm from the root tip. Teeth with a ratio of between 1.4 and 2.8 were included. Teeth were pair matched based on this parameter, and, subsequently, 1 tooth of each pair was randomly assigned to 1 of the 2 projected experimental groups, whereas the other was assigned to the other group. The 2 resulting groups consisted of 14 teeth each that fitted all of the previously mentioned inclusion criteria. The assignment of the procedure to the 2 groups was made by the flip of a coin after the groups had been formed and after an experienced operator had performed root fillings on all teeth (see later). The operator was blinded to the group assignments.

Root Canal Preparation and Filling

All teeth were subjected to chemomechanical preparation of the distal root. An access cavity was prepared in each tooth, and C+ files (Dentsply Maillefer) were used to negotiate the canal. The working length was established 1 mm short of the apical foramen. ProTaper files were used to prepare the canals and were operated with the VDW Gold motor (VDW GmbH, Munich, Germany) at a speed of 300 rpm and a torque of 300 Ncm. The coronal orifices of the distal canals were enlarged using ProTaper SX files (Dentsply Maillefer) that were inserted to a depth of 5 mm from the canal orifice. Subsequently, S1 and S2 files were used to the working length and followed by F1 and F2, which were used to the working length as well. The SX, S1, and S2 were operated with a brushing motion according to the shape of the canals. A syringe with a 27-G needle was inserted to 2 mm short of the entire working length, and the canal was irrigated with 1 mL sodium hypochlorite after each instrumentation. The canals were subsequently irrigated with 2 mL 17% EDTA and were dried using paper points.

Root filling was performed with tapered gutta-percha master cones (ProTaper) and AH Plus sealer (Dentsply DeTrey, Konstanz, Germany) following the lateral compaction method. A lentulo spiral was used to fill the canal with sealer. After insertion of the master cone, accessory gutta-percha cones were added with a #25 finger spreader (Dentsply Maillefer). Any excess of gutta-percha was removed with a hot excavator at the level of the canal orifice. The sealer was allowed to set for 30 days at 37°C and 100% humidity. All teeth were subsequently scanned again, and the volume of root filling was determined (see later).

Retreatment: ProTaper

The retreatment procedure consisted of 2 stages. First, the bulk of the root filling material was removed using ProTaper retreatment

instruments, which was followed by the removal of the remaining material using the F1 and F2 ProTaper files.

Stage 1. ProTaper Universal retreatment files D1-D3 (Dentsply Maillefer) were used to remove the root filling material. The files were operated with the VDW Gold motor with a torque of 300 Ncm and a rotation speed of 180 rpm for D1 and 150 rpm for D2 and D3. D1 was used from the coronal to the middle thirds until no debris was visible on the file surface when it was removed from the canal (18). A drop of chloroform (10 μ L) was placed in the canal, and the D2 instrument was used to 2 mm short of the working length. Next, the canal was irrigated with 2 mL 5.25% NaOCl followed by 2 mL 17% EDTA, which were delivered with a syringe and a 27-G needle. The canal was subsequently dried with paper points, and another drop of 10 μ L chloroform was placed in the canal. Next, the D3 instrument was inserted to the working length using the previously mentioned endpoint criterion. Subsequently, the canal was irrigated with 2 mL 5.25% NaOCl followed by 2 mL 17% EDTA.

Stage 2. F1 and F2 ProTaper files were used with an added brushing motion because of the shape of the canal. Irrigation with 1 mL 5.25% NaOCl and 1 mL 17% EDTA was performed after each instrumentation. A total of 20 μ L chloroform, 8 mL 5.25% NaOCl, and 8 mL 17% EDTA were used for the entire procedure. The time required to accomplish this procedure was recorded using a stopwatch.

The canals were subsequently washed with 2 mL distilled water, dried with paper points, and stored at 100% humidity at room temperature. The retreatment procedure was performed by an operator who had extensive clinical experience with this type of procedure (SYO). The retreatment files were replaced after every 2 retreatment procedures. Next, teeth were scanned again, and the volume of the remaining radiopaque residue was determined (see later).

Retreatment: Profile and SAF

The retreatment procedure consisted of 2 stages. First, the bulk of root filling material was removed with the ProFile instrument, which was followed by the removal of any remaining material using the SAF with sodium hypochlorite and chloroform.

Stage 1. A ProFile rotary file (#25 with a .06 taper, 25 mm, Dentsply Maillefer) was used to remove the bulk of the root filling material (3, 5). It was operated with an X-Smart motor (Dentsply Maillefer) at a torque of 2.4 Ncm and a speed of 600 rpm. Pecking and brushing motions were applied to remove the gutta-percha down to the working length.

Stage 2. After the removal of the bulk of the root filling material, the SAF (2.0-mm diameter) was used. The SAF was operated with an X-Smart motor adapted with a 1:1 gear (NSK, Tochigi, Japan) and a vibrating RDT3-NX handpiece head (ReDent). The rotation speed was set to 5,000 rpm, which resulted in 5,000 in-and-out vibrations per minute with an amplitude of 0.4 mm. Using a VATEA peristaltic pump (ReDent), which was connected to the hollow SAF via a silicone tube, continuous irrigation was applied when indicated. A 4% NaOCl solution was used with a flow rate of 4 mL/min.

First, the SAF was operated in the canal for 1 minute under sodium hypochlorite irrigation to remove coarse particulate material. Next, the canal was dried with paper points and filled with 10 μ L chloroform before the SAF was operated in the canal for an additional minute without any irrigation (the VATEA pump turned off). Subsequently, the canal was refilled with 10 μ L chloroform, and the SAF was operated in it again for 1 minute. Next, the pump was turned on, and the SAF operated with sodium hypochlorite irrigation for 30 seconds. The canal was subsequently flushed with 1 mL 17% EDTA, which was left in the canal while the SAF operated in it for another 30 seconds with the pump turned off. A total of 20 μ L chloroform, 1 mL 17% EDTA, and 6 mL

NaOCl 4% was used for the entire procedure. The time required for this procedure was recorded using a stopwatch.

The canals were subsequently washed with 2 mL distilled water, dried with paper points, and stored at 100% humidity at room temperature. This 2-stage retreatment procedure was performed by an operator who had extensive clinical experience with this type of procedure (MS). The teeth were scanned again (see later), and the volume of the remaining radiopaque residue was determined.

Micro-CT Measurements and Evaluations

Using the μ CT 40 system, 3 high-resolution scans were performed per tooth at the following time points:

1. After canal instrumentation
2. After root filling
3. After the retreatment procedure

Teeth were scanned at 70 kV and 114 μ A with an isotropic resolution of 20 μ m, resulting in 600 to 800 slices per root. High-resolution scans after root canal filling and retreatment procedures were run with a 5-fold integration time to reduce the noise and the scattering effect provoked by radiopaque root filling materials. The volume of interest was selected extending from the distal root canal orifice to the apex of the root.

After determining the region of interest, all teeth were 3D reconstructed. Based on the different radiopacity of root dentin, gutta-percha, and the AH Plus sealer used in the current study, it was possible to differentiate between these entities on μ CT scans (19). Grayscale ranges were determined for each material based on individual scans. To visualize the different materials, these were depicted in false colors in the 3D reconstructions of the μ CT scans using specific software (VGStudio Max 2.1; Volumegraphics, Heidelberg, Germany). Volumes of root fillings before and after the retreatment procedures were calculated using specially developed software (IPL V5.06B, Scanco Medical).

Data Presentation and Statistical Analysis

Data pertaining to the canal shape before preparation were expressed as the ratio of the buccolingual and mesiodistal canal diameter at 6 mm coronal of the root tip. The filled root canal volume was expressed in cubic millimeters. These data were normally distributed (the Shapiro-Wilk test) and are thus presented as means \pm standard deviations.

The remaining root filling volumes after the different retreatment procedures were expressed both in cubic millimeters and as a percentage of the total initial root filling volume. The data were skewed, thus compared using the Wilcoxon test and presented as median values and interquartile ranges (IQRs). For all statistical analyses, a commercially available computer program (JMP; SAS Institute Inc, Cary, NC) was used with the alpha-type error set at 5% ($P < .05$). In addition, another clinically oriented parameter was used and arbitrarily defined canals as “effectively cleaned” when less than 0.5% of root filling residue was left in the canal.

Results

The mean initial ratio of the buccolingual diameter to the mesiodistal diameter of the canal was 1.93 ± 0.38 in the ProTaper group and 2.03 ± 0.49 in the ProFile and SAF group. The difference was not statistically significant. The mean volumes of the root filling were 6.86 ± 1.60 mm³ and 7.89 ± 2.34 mm³ in the ProTaper group and the ProFile and SAF group, respectively. The groups did not differ from each other in either of these parameters (Student *t* test, $P > .05$). Therefore, a similar level of potential challenge was presented to each of the 2 retreatment protocols.

The mean time required to complete the ProTaper retreatment protocol was 10.1 (± 0.3) min with a range of 8.9 to 11.9 minutes. The mean time required to complete the ProFile/SAF protocol was 4.8 (± 0.1) minutes with a range of 4.5 to 5.0 minutes ($P < .01$). Of the total time required for the ProTaper protocol, the instrumentation alone lasted 5.5 (± 0.2) minutes, whereas the irrigation required 4.6 (± 0.2) minutes. These 2 procedures could not be timed individually in the second group because instrumentation and irrigation were performed simultaneously.

None of the procedures removed all the remains of the root canal filling in all teeth. The volume of root filling residue in both groups did not have a normal distribution, and the data were skewed in both groups (Shapiro-Wilk test). The median volume of the root filling residue was 0.38 mm³ (IQR = 0.43) and 0.03 mm³ (IQR = 0.14) in the ProTaper retreatment and ProFile and SAF groups, respectively (Wilcoxon test, $P < .001$).

These residue volumes represented 5.39% (IQR = 4.71) and 0.41% (IQR = 1.64) of the original root filling volume, respectively (Wilcoxon test, $P < .001$, Fig. 1). Reconstructed images of both groups are presented in Figure 2. Among the roots in the ProFile and SAF group, 57% presented with “effectively cleaned” canals (ie, the root filling residue was less than 0.5% of the original root filling volume). In contrast, none of the teeth in the ProTaper group were deemed as “effectively cleaned.”

Discussion

None of the retreatment methods that were tested in the present study could render all canals completely free of root filling residues. However, the ProFile and SAF protocol left significantly less residue and required less time than the ProTaper retreatment protocol (Figs. 1 and 2). The 2 protocols were compared based on a single parameter, which was their ability to remove the root filling without enlarging the root canal, particularly in the apical part. The protocols were compared as complete protocols as suggested by the manufacturers and as clinically daily used by each of the operators with no attempt to analyze their components separately. Such a comparison was beyond the scope of the present study.

The canal was originally prepared to the working length with an F2 ProTaper instrument. Therefore, the D3 instrument, with its size 20 tip, could not be expected to completely remove the apical part of the root filling. The manufacturer’s instructions for the ProTaper retreatment

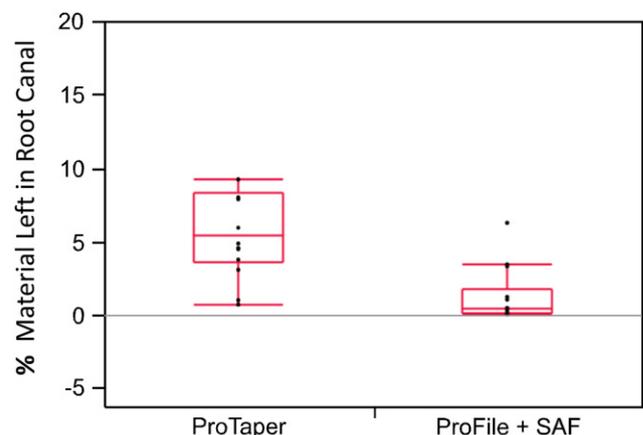


Figure 1. The percent of residual root filling material that was left in the canal after retreatment. The percent of residual root filling material that was left in the canal after removal with ProTaper retreatment files followed by F1 and F2 ProTaper files compared with removal with ProFile followed by SAF.

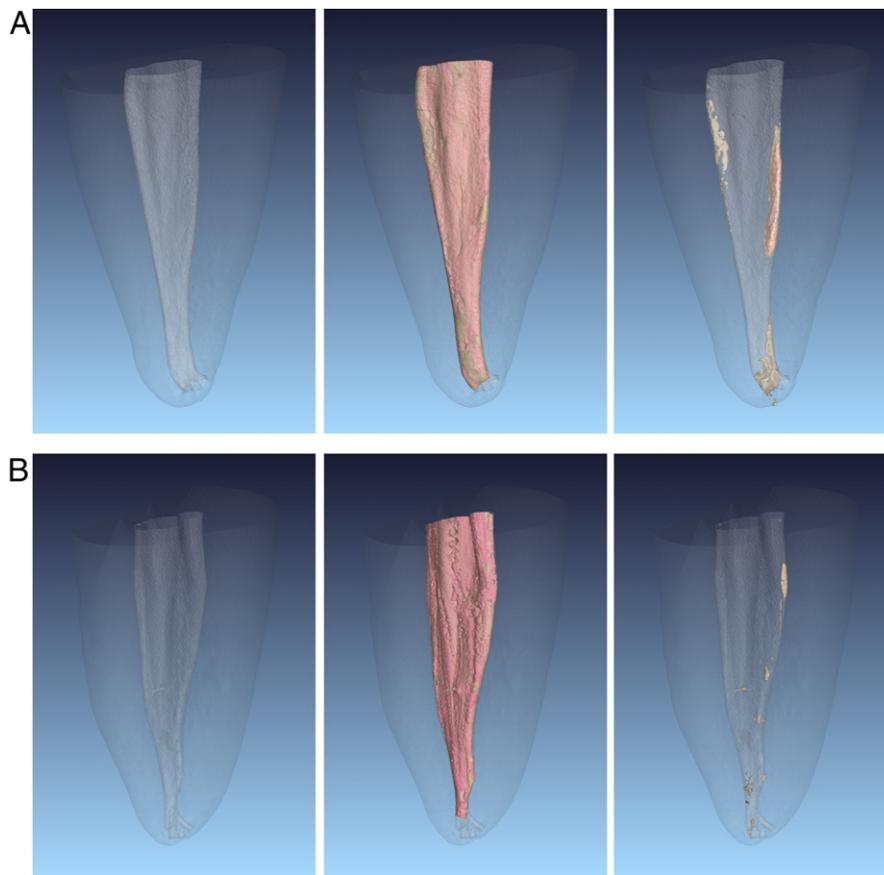


Figure 2. Representative cases of root filling removal. In the 3D reconstructions, gutta-percha is depicted in pink and the sealer in light brown. (A) Root filling residue that remained in the canal after retreatment with ProTaper. *Left*, the canal after preparation; *center*, the root filling after obturation; *right*, the root filling residue left in the canal after retreatment with ProTaper. (B) The root filling residue that was left in the canal after retreatment with Profile and SAF. *Left*, the canal after preparation; *center*, the root filling after obturation; *right*, the root filling residue left in the canal after retreatment with Profile and SAF.

files were followed with some modifications. F1 and F2 instruments were used to remove the remaining root filling material in the apical section after the D3 instrument had been used. The initial preparation of the canals before obturation was limited to F2 because it was estimated that larger preparation may have presented the ProTaper retreatment files with an even greater challenge because the D3 instrument has a size 20 tip (12).

The ProFile and SAF protocol was a modification of a protocol recently suggested and studied by Abramovitz et al (12). A size 25 ProFile instrument with a .06 taper was used because its apical part is similar in size to that of the F2 ProTaper (size 25) with a smaller taper (.06 compared with .08, respectively). Each of the protocols consisted of a 2-stage procedure. In both procedures, the aim of the first stage was to remove the bulk of the root filling material to the working length. The aim of the second stage was to remove the root filling residue remaining in the canal. Each of the compared protocols was used as recommended by the manufacturer and used daily by each of the operators who have extensive clinical experience with the protocols they used. Consequently, small changes in the amount and concentration of the irrigant existed between them; nevertheless, it is unlikely that these differences affected the results.

Several studies have shown that retreatment with either ProFile or ProTaper retreatment files alone failed to render the canals free of residue (4, 5, 10–12). When Abramovitz et al (12) used only ProTaper retreatment files in curved canals of mesial roots of mandibular molars, they found large amounts of residual root filling material in the apical

third of the canals. This result should have been expected because these researchers initially prepared the apical size of the canal to a size of 30 to 45, whereas the tip of the D3 retreatment file has a size of 20 with a .07 taper. Therefore, the manufacturer’s instructions for ProTaper files indicate that whenever the apical diameter of the canal is larger than the tip of the D3 retreatment file, the root filling material that is left in the canal after its use should be removed with a different instrument.

In the present study, this procedure was performed in the ProTaper group using F1 and F2 ProTaper files (apical size 20 with .07 taper and apical size 25 with .08 taper, respectively), which constituted the second stage of the ProTaper retreatment procedure. Larger ProTaper files, such as the F3 (apical size 30 with a .09 taper), were avoided for the following reasons:

1. They may alter the shape of the canal, which was not the aim of this study.
2. When using such a stiff instrument, one may run the risk of canal transportation (20).
3. It has recently been suggested that such procedures may increase the incidence of microcracks in the root dentin (21, 22).

The bulk of the root filling material was removed in the other group using ProFile instruments with an apical size 25 and a .06 taper as suggested by the SAF manufacturer. This approach was used to maintain the original dimensions of the canal as explained previously. The second stage in this group was performed with an SAF instrument. The SAF is supposed to adapt to the cross-section of the canal and to

have a scrubbing effect on the canal walls (15, 16, 23, 24). However, it has been shown by Peters et al (25) that in large canals the 1.5-mm diameter SAF was less effective than the SAF with a 2.0-mm diameter. Therefore, in the present study, a SAF with a 2.0-mm diameter was selected instead of 1 with a 1.5-mm diameter, which was used by Abramovitz et al (12).

The present results indicate that the retreatment protocol of ProFile size 25 .06 followed by the 2.0-mm SAF was more effective than that of ProTaper retreatment files followed by ProTaper F1 and F2 instruments. This approach required less time to accomplish the procedure and resulted in cleaner canals as defined by the amount of residual root filling material. Furthermore, based on our arbitrary definition, more cases in the ProFile and SAF group could be called “effectively cleaned” (ie, having less than 0.5% residue) than in the ProTaper group.

The chloroform that was used at the second stage of the ProFile and SAF procedure was aimed initially for softening of the gutta-percha component of the filling. However, a recent study indicates that softening of the sealer may also have occurred (26), which, in turn, may have contributed to the previously described results by allowing the SAF to scrub the softened sealer off the canal walls.

The present study differs from that of Abramovitz et al (12) because the latter used planar 2D radiographs to evaluate the results. Kfir et al (11) recently reported that such radiographs fail to represent the real cleanliness of the canals compared with evaluating the remains of the root filling by direct visualization using microscopy. Therefore, the current study used 3D high-resolution micro-CT scanning as the evaluation tool. This tool has previously been used to evaluate the 3D quality of root canal fillings (17).

Neither retreatment protocol could render all canals completely free of root filling residues. Nevertheless, under the conditions of the present study, retreatment with ProFile #25 .06 followed by the SAF resulted in less residual root filling material than retreatment with ProTaper retreatment files followed by ProTaper F1 and F2 instruments. It is of interest to note that when an arbitrarily selected less than 0.5% cutoff point was used to define “effectively cleaned” canals, more than half of the canals in the ProFile and SAF group were considered “effectively cleaned” compared with none in the ProTaper group.

Acknowledgments

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

References

1. Bergenholz G, Lekholm U, Milthorn R, Heden G, Odesjo B, Ergostrom B. Retreatment of endodontic fillings. *Scand J Dent Res* 1979;87:217–24.
2. Stabholz A, Friedman S. Endodontic retreatment-case selection and technique, part 2: treatment planning for retreatment. *J Endod* 1988;14:607–14.
3. Sae-Lim V, Rajamanickam I, Lim BK, Lee HL. Effectiveness of ProFile .04 taper rotary instruments in endodontic retreatment. *J Endod* 2000;26:100–4.

4. Imura N, Kato AS, Hata G-I, Uemura M, Toda T, Weine F. A comparison of the relative efficacies of four hand and rotary instrumentation techniques during endodontic retreatment. *Int Endod J* 2000;33:361–6.
5. Baratto Filho F, Ferreira EL, Fariniuk LF. Efficiency of the 0.04 taper ProFile during the re-treatment of gutta-percha-filled root canals. *Int Endod J* 2002;35:651–4.
6. Hülsmann M, Bluhm V. Efficacy, cleaning ability and safety of different rotary NiTi instruments in root canal retreatment. *Int Endod J* 2004;37:468–76.
7. de Carvalho Maciel AC, Zaccaro Scelza MF. Efficacy of automated versus hand instrumentation during root canal retreatment: an ex vivo study. *Int Endod J* 2006;39:779–84.
8. Gu L-S, Ling J-Q, Wei X, Huang X-Y. Efficacy of ProTaper Universal rotary retreatment system for gutta-percha removal from root canals. *Int Endod J* 2008;41:288–95.
9. Taşdemir T, Er K, Yildirim T, Çelik D. Efficacy of three rotary NiTi instruments in removing gutta-percha from root canals. *Int Endod J* 2008;41:191–6.
10. Saad AY, Al-Hadlaq SM, Al-Katheeri NH. Efficacy of two rotary NiTi instruments in the removal of gutta-percha during root canal retreatment. *J Endod* 2007;3:38–41.
11. Kfir A, Tsesis I, Yakirevich E, Matalon S, Abramovitz I. The efficacy of five retreatment techniques: microscopic vs. radiographic evaluation. *Int Endod J* 2012;45:35–41.
12. Abramovitz I, Relles-Bonar S, Baransi B, Kfir A. The effectiveness of a self-adjusting file to remove residual gutta-percha after retreatment with rotary files. *Int Endod J* 2012;45:386–92.
13. de Chevigny C, Dao TT, Basrani BR, et al. Outcome in endodontics: The Toronto Study-Phases 3 and 4: orthograde retreatment. *J Endod* 2008;34:131–7.
14. De-Deus G, Souza EM, Barino B, et al. The self-adjusting file optimizes debridment quality in oval-shaped root canals. *J Endod* 2011;37:701–5.
15. Metzger Z, Teperovich E, Zary R, Cohen R, Hof R. Respecting the root canal: a new concept of a self-adjusting file (SAF). *J Endod* 2010;36:679–90.
16. Hof R, Perevalov V, Eltanani M, Zary R, Metzger Z. The self-adjusting file (SAF). Part 2: mechanical analysis. *J Endod* 2010;36:691–6.
17. Metzger Z, Zary R, Cohen R, Teperovich E, Paqué F. The quality of root canal preparation and root canal obturation in canals treated with rotary versus self-adjusting files: a three-dimensional micro-computed tomographic study. *J Endod* 2010;36:1569–73.
18. Schirrmeister JF, Hermanns P, Meyer KM, Goetz F, Hellwig E. Detectability of residual Epiphany and gutta-percha after root canal retreatment using a dental operating microscope and radiographs: an ex vivo study. *Int Endod J* 2006;39:558–65.
19. Jung M, Lommel D, Klimek J. The imaging of root canal obturation using micro-CT. *Int Endod J* 2005;38:617–26.
20. Kunert GG, Camargo VR, Fontanella VRC, de Moura AAM, Barletta FB. Analysis of apical root transportation associated with ProTaper Universal F3 and F4 instruments by using digital subtraction radiography. *J Endod* 2010;36:1052–5.
21. Shemesh H, Roeleveld AC, Wesselink PR, Wu MK. Damage to root dentin during retreatment procedures. *J Endod* 2011;37:63–6.
22. Adorno CG, Yoshioka T, Suda H. Crack initiation on the apical root surface caused by three different nickel-titanium rotary files at different working lengths. *J Endod* 2011;37:522–5.
23. Peters OA, Paqué F. Root canal preparation of maxillary molars with the Self-adjusting File: A micro-computed tomography study. *J Endod* 2011;37:53–7.
24. Versiani MA, Pécora JD, de Sousa-Neto MD. Flat-oval root canal preparation with Self-Adjusting File instrument: a micro-computed tomography study. *J Endod* 2011;37:1002–7.
25. Peters OA, Boessler C, Paqué F. Root canal preparation with a novel nickel-titanium instrument evaluated with micro-computed tomography: canal surface preparation over time. *J Endod* 2010;36:1068–72.
26. Kfir A, Rosenberg E, Tamse A, Tsesis I. Can epoxy-resin-based endodontic sealers be softened within 1-2 min? An *in vitro* study with chloroform and xylene. *ENDO* (in press).