ORIGINAL ARTICLE

UDC: 616.31
DOI: https://doi.org/10.2298/VSP210307053V

Influence of solvent use on apical extrusion during removal of Resilon™ from root canals

Uticaj rastvarača na apikalnu ekstruziju tokom uklanjanja *Resilon*™ iz kanala korena zuba

Karolina Vukoje, Tanja Veljović, Jelena Mirnić, Aleksandra Maletin, Ana Tadić

University of Novi Sad, Faculty of Medicine, Department of Dental Medicine, Novi Sad, Serbia

Abstract

Background/Aim. During retreatment, filling material and debris may extrude and trigger an inflammatory reaction of periapical tissues. Resilon™ has not been investigated in terms of solvent use and influence on apical extrusion during retreatment. The aim of the study was to evaluate the amount of apically extruded debris during Resilon™ removal using ProTaper (PT), Twisted File (TF), and Hedstrom instruments, with and without solvent. **Methods.** In total, 72 extracted teeth with single canals were used. Canals were prepared with PT Universal (F2) and filled with Resilon™ and RealSeal sealer before being assigned randomly to 6 groups (n = 12 in each group). Retreatment in Groups 1–3 was done with PT, TF, or Hedstrom instruments, without solvent. In Groups 4–6, the same instruments were used with chloroform. Apically extruded debris was collected in a simulated periapical environment and assessed visually. Additionally, the time required for retreatment was recorded. Data were analyzed statistically using the Mann-Whitney *U* test, with a significance level of 0.05. **Results.** There were no significant differences in apical extrusion debris between groups ($p > 0.05$) regarding solvent use. Rotary instruments, without solvent, were associated with significantly less debris extrusion when compared with hand files ($p < 0.05$). When solvent was used, rotary instruments caused a higher degree of extruded material, which was similar to the results of hand instruments. **Conclusion.** The use of rotary instruments without solvent resulted in a lower degree extrusion of Resilon ™ material compared to hand instruments, while greater caution is advised in the presence of solvent when rotary instruments are used to remove this material.

Key words:
dental instruments; resilon sealer; root canal filling materials; solvents.

Apstrakt

Uvod/Cilj. Tokom endodontskog retretmana, ostaci materijala za punjenje mogu biti istisnuti kroz apikalni otvor zuba i izazvati inflamacijsku reakciju periapikalnih tkiva. Upotreba rastvarača i njegov uticaj na apikalnu ekstruziju tokom uklanjanja *Resilon*™ nisu ispitivani. Cilj rada bio je da se proceni apikalna ekstruzija ostataka tokom uklanjanja *Resilon*™, primenom instrumenata *ProTaper* (PT), *Twisted File* (TF) i *Hedstrom*, sa i bez upotrebe rastvarača. **Metode.** Korišćena su 72 izvađena zuba sa po jednim kanalom. Kanali su obrađeni instrumentima PT *Universal* (F2) i opturisani *Resilon*™ i *RealSeal* silerom, pre nego što su nasumično podeljeni u 6 grupa (n = 12 u svakoj grupi). Retretman u grupama 1–3 urađen je PT, TF ili *Hedstrom* instrumentima, bez rastvarača. U grupama 4–6 korišćeni su isti instrumenti sa hloroformom. Apikalno istisnuti ostaci sakupljeni su u simuliranom periapikalnom okruženju i procenjeni vizuelno. Pored toga, zabeleženo je vreme potrebno za retretman. Podaci su statistički analizirani korišćenjem *Mann-Whitney U* testa, sa nivoom značajnosti $p < 0,05$. **Rezultati.** Nije bilo značajnih razlika u rezultatima apikalne ekstruzije ($p > 0,05$) u zavisnosti od upotrebe rastvarača. Rotirajući instrumenti, primenjeni bez rastvarača, doveli su do značajno manje ekstruzije u poređenju sa ručnim turpijama ($p < 0,05$). Kada je korišćen rastvarač, rotirajući instrumenti, slično ručnim instrumentima, doveli su do većeg stepena ekstruzije materijala. **Zaključak.** Upotreba rotirajućih instrumenata bez rastvarača dovela je do manjeg stepena ekstruzije *Resilon*™ materijala u poređenju sa ručnim instrumentima, dok se u prisustvu rastvarača savetuje veći oprez pri upotrebi rotirajućih instrumenata za uklanjanje ovog materijala.

Ključne reči:
stomatološki instrumenti; resilon, materijal za punjenje korenskog kanala; zub, materijali za punjenje korenskog kanala; rastvarači.

Correspondence to: Karolina Vukoje, University of Novi Sad, Faculty of Medicine, Department of Dental Medicine, Hajduk Veljkova 3, 21 000 Novi Sad, Serbia. E-mail: karolina.vukoje@mf.uns.ac.rs

Introduction

When endodontic therapy fails and retreatment is required, the removal of filling material can be a challenging procedure [1]. During root canal retreatment, filling material, necrotic pulp tissue, bacteria, irrigants, and solvents may extrude beyond the apical foramen and trigger an inflammatory reaction of the periapical tissues [2, 3]. As an undesirable consequence, postoperative pain, swelling and inter-appointment flare-up, delayed healing, or even treatment failure may occur [4, 5]. Therefore, reducing the risk of debris extrusion into the periradicular tissues would be beneficial for both the patient and the clinician [6].

The most widely used material for root canal obturation is gutta-percha. However, since 2004, a new thermoplastic synthetic polymer material – Resilon™ (Resilon™ Research LLC, Madison, CT) has been available. The material behaves like gutta-percha and adheres to the root canal walls, forming a "monoblock" and reducing microleakage [7–9]. Although canal wall cleanliness after Resilon™ removal was examined in several studies, there are only a few studies in the current literature that evaluate the apical extrusion (AE) of this material during retreatment in terms of different instruments or different obturation techniques used [10–14]. Furthermore, to the best of our knowledge, the effect of solvent use on AE during Resilon™ removal has not been assessed until now. Likewise, these studies only measure the amount of apically extruded material without any simulation of the resistance that the periapical tissues offer in clinical *in vivo* conditions.

Another very recent and important finding should be emphasized. The latest long-term clinical studies indicate that, compared with gutta-percha, teeth obturated with Resilon™ have greater odds of failure, most probably due to the susceptibility of this material to degradation [15–17]. These data suggest that, in the years to come, a greater need for retreatment of teeth obturated with Resilon™ may appear. In light of these findings, the results of this study that investigated the AE of Resilon™ during retreatment and the use of solvent could be found useful by clinicians.

It is generally accepted that none of the instruments or techniques used can prepare root canals or remove obturation material without producing some apically extruded debris. However, the amount of apically extruded debris might vary according to the technique used and the design of the root canal instrument [18, 19]. Instrument systems have been developed specifically for retreatment procedures. ProTaper (PT) Universal Retreatment (Dentsply Maillefer, Ballaigues, Switzerland) is a rotary system made of nickel-titanium (Ni-Ti) and consists of three instruments (D1, D2, D3) used for the removal of filling material from each third of the root canal, respectively. Likewise, a new type of instrument – Twisted File (TF) (SybronEndo, Orange, CA, USA) has become available but has not been specifically designed for retreatment. These files have a twisted design, a triangular cross-section, variable pitch, a safe-ended tip, and no ground surface treatment [20]. According to the manufacturer, this design allows their use in retreatment cases. Only a few studies evaluate the cleaning efficacy of TF instruments in retreatment procedures [21, 22] and the influence of this instrument on AE during retreatment [23].

The aim of the study was to evaluate *in vitro* the amount of apically extruded debris during retreatment of Resilon™-filled root canals, using PT, TF, and Hedstrom instruments, with or without solvent.

Methods

Specimen selection

In total, 72 freshly extracted human mandibular single-rooted incisor teeth with one straight canal (curvatures < 10°), with mature apices, were used. Radiographs were taken to confirm that there was no previous root canal treatment, internal resorption, or root canal calcification. To standardize specimen lengths, teeth were shortened to 16 mm by removing the crown.

Root canal preparation and obturation

Canal patency was confirmed with a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) until it was visible at the apical foramen. The working length (WL) was 1 mm short from the observed length. All teeth were prepared with a rotary PT Universal system (Dentsply Maillefer, Ballaigues, Switzerland) to size #25 (F2). Irrigation with 2 mL of 5.25% sodium hypochlorite (NaOCl-Chloraxid, Cerkamed Company, Stalowa Wola, Poland) was used between each instrument. The smear layer was removed with 5 mL of 17% ethylenediaminetetraacetic acid (EDTA) (Endo Solution, Cerkamed Company), followed by a rinse with 10 mL of distilled water. After drying with paper points (PT F2, Dentsply Maillefer), master Resilon™ cone size #25.06 (RealSeal 0.06 taper points, SybronEndo, Kerr Corporation, USA) was fitted to the WL to check tug-back. The root canal walls were coated with a self-etching primer using a microbrush, and the excess was removed with paper points. The master cone was coated with an adhesive, methacrylate sealer (RealSeal Root Canal Sealant, SybronEndo Kerr Corporation, USA) and obturated using cold lateral condensation and accessory Resilon™ cones. The excess cones coronally were removed with a heated instrument, and additional vertical condensation was done using pluggers (Dentsply Maillefer). The coronal surface was then light cured with Woodpecker LED.H curing light (Guilin Woodpecker Medical Instruments, China; 12,000 mW/cm^2, S/N:L1390416H) for 40 sec, according to the manufacturer's instruction. Access openings were sealed (Cavit; 3M ESPE, Seefeld, Germany), and obturation quality was confirmed by radiographs from two directions. All teeth were stored at 37 °C in 100% humidity for six weeks to allow the complete setting of the sealer and the aging of the material to some extent. The temporary filling material was replaced every two weeks to maintain a good seal throughout the material seating procedure.

The teeth were coded and randomly assigned into six groups (n = 12). In each group, Gates-Glidden drills (#3) were used to remove 2 mm of material from the coronal portion.

Retreatment techniques

Group 1: ProTaper

PT Universal Retreatment (Dentsply, Maillefer) instruments were applied sequentially, using the D1 file (#30/.09) to remove filling material from the coronal third, whereas D2 (#25/.08) and D3 files (# 20/.07) were used in the middle and the apical third, respectively. The instruments were used in a brushing action with lateral pressing movements, with a rotational speed of 600 rpm (X-Smart, Dentsply Maillefer), according to the manufacturer's instructions. Additional apical preparation was performed with PT Universal instruments F3 (#30) and F4 (#40) at 300 rpm.

Group 2: Twisted File

TF (SybronEndo) instruments were used in the following sequence: TF 35 (0.06 taper), followed by TF 30 and 25 (0.08 taper), until reaching the WL. The rotational speed of the X-Smart motor was set at a maximum of 800 rpm. Finally, TF 35 (0.06 taper) and 40 (0.04 taper) were used to enlarge the apical preparation and additionally clean the canal walls, with a rotational speed of 500 rpm. All the instruments were used with a gentle, in-and-out motion and without pressure, according to the manufacturer's instructions.

Group 3: Hedstrom

Retreatment was performed with Hedstrom files (Dentsply Maillefer) sequentially from #40–20 in a circumferential quarter-turn, push-pull filing motion until the WL was reached. Re-preparation of the canal apical part was carried out till size 40.

Group 4: ProTaper + solvent

The same instrumentation protocol as in Group 1 was used. Resilon™ was previously softened using 0.05 mL of chloroform (Merck, Darmstadt, Germany) for 1 min. This procedure was repeated also in the middle and apical portion of the canal (0.15 mL in total for each specimen). Instruments during material removal were used in the presence of a solvent, except in the apical third, where the excess solvent was collected with paper points before instrumentation. When the WL was reached, the use of solvent was discontinued during re-preparation and apical enlargement.

Group 5: Twisted File + solvent

The same instrumentation protocol as in Group 2 was used, and the solvent was used in the same manner as explained in Group 4.

Group 6: Hedstrom + solvent

The same instrumentation protocol as in Group 3 was used, and the solvent was used in the same manner as explained in Group 4.

Each set of instruments was used to retreat maximally four root canals and then discarded. All instruments were used according to the manufacturer's instructions. During retreatment, the flutes of the instruments were frequently cleaned, and 2 mL of 5.25% NaOCl was used for irrigation after each instrument. Retreatment was considered complete when the WL was reached, and no more material was observed on the instrument or in the irrigating solution. After re-preparation, the canals were irrigated with 5 ml of 17% EDTA for 1 min and then flushed with 10 mL of distilled water. A single experienced operator performed all the root canal procedures to reduce inter-operator variability.

Measurement of collected debris and time for retreatment

Prior to retreatment, the apex of the teeth was covered with Teflon foil, and a ball of soft blue wax was pushed over it. The Teflon served to prevent the wax from being pushed into the apical foramen. This setup was done in order to simulate the resistance offered by the periapical tissues and secure the material extruded through the apical foramen to be flushed away with irrigating solutions used during retreatment. Extrusion of root canal filling material through the apical foramen was detected visually after removal of the debris collection apparatus using loupes with x3 magnification. Scoring was carried out by a second examiner, who was blinded to the group assignment, according to the following system [10, 24]: 0 = no extrusion of filling material through the foramen; 1 = minimal extrusion of filling material, barely detectable; 2 = moderate extrusion of filling material, easily detectable; 3 = extrusion of a considerable amount of filling material.

Additionally, the time required for the retreatment procedures was recorded (in sec) for each sample. The time for irrigation, solvent application, cleaning, and changing of instruments was not recorded.

Statistical analysis

Mean ranks of scores for apically extruded material were calculated and analyzed statistically using the Mann-Whitney *U* test. Data for the retreatment time were analyzed with one-way ANOVA. Analysis was performed with SPSS (version 20.0) at a significance level of $p < 0.05$.

Results

The mean rank of scores for AE and the mean retreatment time data are presented in Tables 1 and 2. The use of solvent had no statistically significant effect on the results of AE between the groups ($p = 0.691$; Table 1). When no solvent was used, the difference between tested instruments was statistically significant ($p = 0.013$), and Hedstrom files extruded more debris when compared with PT ($p = 0.023$) and TF rotary systems ($p = 0.011$; Table 2). When solvent was used, all three tested instruments caused a similar degree of apically extruded material ($p = 0.974$; Table 2).

The time for retreatment decreased significantly when the solvent was used compared to the removal of Resilon™ without solvent ($p < 0.01$; Table 1). The time needed for retreatment with the same type of instrument was significantly shorter when the solvent was used. Ro-

Table 1

Mean rank of scores for apical extrusion during Resilon™ removal and mean retreatment time

Group	Mean rank	Sum of ranks	Mean time (s) ± SD
Resilon™ – without solvent (Groups 1–3)	29.65	889.50	168.37 ± 121.48
Resilon™ – with solvent (Groups 4–6)	31.35	940.50	61.60 ± 34.81*

Number of participants = 72 (six groups of 12 participants each); SD – standard deviation.
*** $p < 0.01$ compared to groups 1–3 (without solvent).**

Table 2

Mean rank of scores for apical extrusion and mean retreatment time for each group

Group		Mean rank	Mean time (s) ± SD
number	name		
1	ProTaper without solvent	12.95[a]	124.10 ± 22.92 [a,b,d]
2	Twisted File without solvent	11.80[a]	188.40 ± 50.22 [a,c,d]
3	Hedstrom without solvent	21.75[A]	485.90 ± 103.53 [A,b,c]
4	ProTaper with solvent	15.05	85.60 ± 13.70 [a,b,D]
5	Twisted File with solvent	15.55	95.80 ± 18.46 [b,C]
6	Hedstrom with solvent	15.90	253.10 ± 39.51 [B]

Number of participants = 72 (six groups of 12 participants each); SD – standard deviation.
*** The difference is statistically significant ($p < 0.05$) between results marked with the same pairs of uppercase and lowercase letters (A-a, B-b, C-c, or D-d).**

tary instruments required significantly less time for retreatment than Hedstrom files, regardless of the solvent use ($p < 0.05$; Table 2).

Discussion

As clinical assessment of AE is not viable, laboratory studies are necessary as a helpful approximation to clinical reality [25]. However, caution should be taken during the interpretation of the results because, in the *in vitro* setup, there are no periapical tissues present that may act as a natural barrier [5]. This study used an innovative experimental setup, incorporating a debris collection apparatus that closely covers the root apices and offers some resistance to AE. Similar strategies were employed in other studies [26, 27]. Laboratory studies of AE during retreatment were most often conducted with a quantitative method, which involves the use of a special apparatus for the collection of apically extruded material and debris, and measuring their amount in grams [2, 19, 28–30]. In some studies, the amount of apically extruded filling material during retreatment was detected visually and evaluated with a scoring system [10, 24], as in the presented study. This kind of evaluation methodology can be criticized due to a certain degree of subjectivity and less precision in assessing the extruded material amount. However, the precision of material extrusion measured in grams may be of limited relevance because extrusion may occur more easily and frequently if there is no periapical barrier that would limit the extrusion to some degree, as in clinical reality [27]. Furthermore, in their study, Alves et al. [27] found no correlation between extruded bacterial counts and the volume of debris.

The number of studies evaluating apically extruded debris during Resilon™ retreatment is limited [10–14], and regardless of the methodology used, all can contribute to the clarification of the AE of the Resilon™ material. AE studies during the removal of gutta-percha are numerous, but a comparison of different obturation materials was made only in a few studies, and no statistically significant difference was observed between the tested materials [10, 12, 13]. A study that also used the visual technique [10] and compared gutta-percha, Resilon™, and EndoRez, found no difference between materials in terms of AE. In the study by Çanakçi et al. [11], a different obturation technique (warm vertical condensation) did cause a statistically significant difference for AE; however, in the groups obturated with cold lateral condensation (CLC), there was no difference between AE of gutta-percha and Resilon™. According to the information available to the authors, no study has assessed the impact of solvent use on debris extrusion during Resilon™ removal. Therefore, this study aimed to test only Resilon™ material and evaluate the influence of solvent use and different instruments used for the retreatment protocol (Hedstrom, PT, and TF) when CLC was used as an obturation method.

The results of the current study showed that chloroform use did not have a statistically significant influence on AE during Resilon™ removal. As recommended by the manufacturer for the retreatment of the Resilon™ system, chloroform was used in this study. Moreover, studies confirmed that this material could be effectively removed with chloroform and rotary instruments [31, 32]. In a recent study, the authors concluded that the use of a solvent specific to the sealer during retreatment decreased the amount of apically extruded debris [33]. Studies evaluating the solubility of the Resilon™ system with different solvents, such as xylol [34], and its impact on AE during retreatment, should be conducted.

Other than the type of solvent, the method of use and the quantity of solvent can also influence the AE of the filling material. In the present study, the amount of chloroform

was the same in all groups where the solvent was used (0.15 mL in total for each sample). Retreatment instruments were used in the presence of a solvent, except in the apical third, where the excess solvent was previously collected with paper points. That was done as a precaution that is also recommended in clinical conditions to prevent additional extrusion into periapical tissues and possible solvent toxicity.

The presented results for AE in terms of different instruments used for retreatment showed that rotary instruments caused significantly less AE than Hedstrom files when no solvent was used. There was no difference regarding the amount of AE between the two rotary instruments, which is in accordance with other studies [12, 23]. However, in the present study, during retreatment with solvent, rotary instruments caused a higher degree of material extrusion, which was similar to the extrusion caused by Hedstrom hand files. In most studies, a common finding is that manual instrumentation causes greater extrusion when compared with engine-driven preparation [12, 19, 23, 28, 29]. That is partially in accordance with the results of the presented study when no solvent was used during retreatment. Most studies have concluded that rotary instruments produce less debris extrusion than hand-filing techniques because they tend to pull the debris into the flutes of the instrument and in a coronal direction [2, 10]. However, in this study, regardless of the convenient design, rotary instruments caused similar AE as hand files when the solvent was used. That may be explained by the fact that Resilon™ is a very thermoplastic material [35], and when additionally softened with chloroform and heat generated by the friction of rotary instruments, it can be easily pushed through the apical foramen. This study can add this observation when Resilon™ retreatment is performed and emphasize that rotary instruments should be used with more care in the presence of a solvent to minimize apically extruded debris.

Not many studies measured retreatment time during the use of different instruments, and mainly these studies evaluated gutta-percha removal. The results of this study showed that retreatment time was significantly reduced with chloroform use. Because of the limited number of studies that evaluated Resilon™ retreatment and measured working time [13], other studies investigating these factors and different types of solvents should be conducted.

The results also showed that the longest retreatment time was needed with hand instruments, regardless of the solvent use, while rotary instruments required significantly less time for retreatment. Somma et al. [10] compared three types of obturating material and Mtwo instruments and also PT rotary instruments with Hedstrom files and concluded that rotary instruments and Resilon™ filling material had a positive impact on reducing the time for retreatment. The study that also evaluated TF for retreatment of Resilon™ reported that Mtwo Retreatment instruments were faster than PT and TF instruments [21]. Another study evaluated the effectiveness of the newer TF Adaptive instruments, but only for gutta-percha removal, and reported that Reciproc and PT Retreatment instruments were more efficient than TF Adaptive instruments and hand files and that the TF Adaptive system was advantageous over hand files only with regard to operating time [22].

Conclusion

Under the experimental conditions of the present study, all tested retreatment systems caused AE. The use of chloroform during Resilon™ removal did not have a significant effect on the results of AE; however, it significantly reduced retreatment time. Rotary instruments caused less AE than Hedstrom files when no solvent was used. Nevertheless, the use of solvent caused a higher degree of extruded material when rotary instruments were used compared to their use without solvent. In accordance with these findings, rotary instruments should be used with precaution for the removal of Resilon™ in the presence of a solvent.

REFERENCES

1. *Zanettini PR, Barletta FB, de Mello Rahde N.* In vitro comparison of different reciprocating systems used during endodontic retreatment. Aust Endod J 2008; 34(3): 80–5.
2. *Huang X, Ling J, Wei X, Gu L.* Quantitative evaluation of debris extruded apically by using ProTaper Universal Tulsa rotary system in endodontic retreatment. J Endod 2007; 33(9): 1102–5.
3. *Siqueira JF.* Microbial causes of endodontic flare-ups. Int Endod J 2003; 36(7): 453–63.
4. *Nair PNR.* On the causes of persistent apical periodontitis: A review. Int Endod J 2006; 39(4): 249–81.
5. *Tanalp J, Güngör T.* Apical extrusion of debris: a literature review of an inherent occurrence during root canal treatment. Int Endod J 2014; 47(3): 211–21.
6. *Romualdo PC, de Oliveira KMH, Nemezio MA, Küchler EC, Silva RAB, Nelson-Filho P,* et al. Does apical negative pressure prevent the apical extrusion of debris and irrigant compared with conventional irrigation? A systematic review and meta-analysis. Aust Endod J 2017; 43(3): 129–37.
7. *Barnett F, Trope M.* Resilon™: A novel material to replace gutta percha. Contemp Esthet Restor Pract 2005; 9(8): 64–7.
8. *Kangarlou A, Dianat O, Esfahrood ZR, Asharaf H, Zandi B, Eslami G.* Bacterial leakage of GuttaFlow-filled root canals compared with Resilon™/Epiphany and Gutta-percha/AH26-filled root canals. Aust Endod J 2012; 38(1): 10–3.
9. *Shipper G, Ørstavik D, Teixeira FB, Trope M.* An evaluation of microbial leakage in roots filled with a thermoplastic synthetic polymer-based root canal filling material (Resilon™). J Endod 2004; 30(5): 342–7.
10. *Somma F, Cammarota G, Plotino G, Grande NM, Pameijer CH.* The effectiveness of manual and mechanical instrumentation for the retreatment of three different root canal filling materials. J Endod 2008; 34(4): 466–9.
11. *Çanakçi BC, Sungur R, Er Ö.* Comparison of warm vertical compaction and cold lateral condensation of α, β gutta-percha and Resilon™ on apically extruded debris during retreatment. Niger J Clin Pract 2019; 22(7): 926–31.
12. *Pešić D, Melih I, Kolak V, Nikitović A, Jakovljević A.* Evaluation of apically extruded debris during removal of gutta-percha and Resilon™ using different instrumentation techniques. Vojnosanit Pregl 2018; 75(1): 56–61. (Serbian)

13. *Vukoje K, Stojšin I, Kantardžić I, Janković O*. Apical extrusion of root canal filling material during the removal of gutta-percha and Resilon™. Serbian Dental J 2020; 67(2): 91–9. (Serbian)
14. *AL-Haddad AY, Che Ab Aziz ZA*. Apically extruded debris during removal of Realseal™ using two re-treatment rotary systems. Austral J Basic Appl Sci 2011; 5(3): 114–9.
15. *Barborka BJ, Woodmansey KF, Glickman GN, Schneiderman E, He J*. Long-term clinical outcome of teeth obturated with Resilon™. J Endod 2017; 43(4): 556–60.
16. *Strange KA, Tawil PZ, Phillips C, Walia HD, Fouad AF*. Long-term outcomes of endodontic treatment performed with Resilon™/Epiphany. J Endod 2019; 45(5): 507–12.
17. *Payne LA, Tawil PZ, Phillips C, Fouad AF*. Resilon: Assessment of degraded filling material in nonhealed cases. J Endod 2019; (6): 691–5.
18. *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(10): 1278–80.
19. *Kustarci A, Altunbas D, Akpinar KE*. Comparative study of apically extruded debris using one manual and two rotary instrumentation techniques for endodontic retreatment. J Dent Sci 2012; 7(1): 1–6.
20. *Gambarini G, Grande NM, Plotino G, Somma F, Garala M, De Luca M,* et al. Fatigue resistance of engine-driven rotary nickel-titanium instruments produced by new manufacturing methods. J Endod 2008; 34(8): 1003–5.
21. *Marfisi K, Mercade M, Plotino G, Duran-Sindreu F, Bueno R, Roig M*. Efficacy of three different rotary files to remove gutta-percha and Resilon™ from root canals. Int Endod J 2010; 43(11): 1022–8.
22. *Akbulut MB, Akman M, Terlemez A, Magat G, Sener S, Shetty H*. Efficacy of Twisted File Adaptive, Reciproc and ProTaper Universal Retreatment instruments for root-canal-filling removal: A cone-beam computed tomography study. Dent Mater J 2016; 35(1): 126–31.
23. *Altunbas D, Kutuk B, Toyoglu M, Kutlu G, Kustarci A, Er K*. Reciproc versus Twisted File for root canal filling removal: assessment of apically extruded debris. J Istanb Univ Fac Dent 2016; 50(2): 31–7.
24. *Betti LV, Bramante CM*. Quantec SC rotary instruments versus hand files for gutta-percha removal in root canal retreatment. Int Endod J 2001; 34(7): 514–9.
25. *Caviedes-Bucheli J, Castellanos F, Vasquez N, Ulate E, Munoz HR*. The influence of two reciprocating single-file and two rotary-file systems on the apical extrusion of debris and its biological relationship with symptomatic apical periodontitis. A systematic review and meta-analysis. Int Endod J 2016; 49(3): 255–70.
26. *Lu Y, Wang R, Zhang L, Li HL, Zheng QH, Zhou XD,* et al. Apically extruded debris and irrigant with two Ni-Ti systems and hand files when removing root fillings: a laboratory study. Int Endod J 2013; 46(12): 1125–30.
27. *Alves FRF, Paiva PL, Marceliano-Alves MF, Cabreira LJ, Lima KC, Siqueira JF Jr,* et al. Bacteria and hard tissue debris extrusion and intracanal bacterial reduction promoted by XP-endo Shaper and Reciproc instruments. J Endod 2018; 44(7): 1173–8.
28. *Topçuoğlu HS, Akti A, Tuncay Ö, Dinçer AN, Düzgün S, Topçuoğlu G*. Evaluation of debris extruded apically during the removal of root canal filling material using ProTaper, D-RaCe, and R-Endo rotary nickel-titanium retreatment instruments and hand files. J Endod 2014; 40(12): 2066–9.
29. *Deonizio MD, Sydney GB, Batista A, Pontarolo R, Guimarães PR, Gavini G*. Influence of apical patency and cleaning of the apical foramen on periapical extrusion in retreatment. Braz Dent J 2013; 24(5): 482–6.
30. *Uezu M, Britto M, Nabeshima C, Pallotta R*. Comparison of debris extruded apically and working time used by ProTaper Universal rotary and ProTaper retreatment system during gutta-percha removal. J Appl Oral Sci 2010; 18(6): 542–5.
31. *De Oliveira DP, Barbizam JVB, Trope M, Teixeira FB*. Comparison between gutta-percha and Resilon™ removal using two different techniques in endodontic retreatment. J Endod 2006; 32(4): 362–4.
32. *Hassanloo A, Watson P, Finer Y, Friedman S*. Retreatment efficacy of the Epiphany soft resin obturation system. Int Endod J 2007; 40(8): 633–43.
33. *Çanakçi BC, Er O, Dincer A*. Do the sealer solvents used affect apically extruded debris in retreatment? J Endod 2015; 41(9): 1507–9.
34. *Bis BM, Silva-Sousa YTC, Macedo LMD, Oliveira OP, Alfredo E, Leoni GB,* et al. Removal of filling material using rotating or reciprocating systems with or without solvent: microCT analysis. Braz Oral Res 2021; 35: e117.
35. *Tanomaru-Filho M, Silveira GF, Tanomaru JMG, Bier CAS*. Evaluation of the thermoplasticity of different gutta-percha cones and Resilon™®. Aust Endod J 2007; 33(1): 23–6.

Received on March 7, 2021
Revised on April 18, 2022
Accepted on May 13, 2022
Online First May 2022