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ORIGINAL ARTICLE

The impact of kinematics, single-file technique and preparation time on the apical extrusion of debris

ABSTRACT

Aim: *To compare canal preparation time and apical extrusion of debris during instrumentation with the ProTaper Next (PTN), HyFlex CM (HCM), HyFlex EDM (HEDM), WaveOne Gold (WOG), and Reciproc Blue (RCB) systems.*
Methodology: *Seventy-five roots of extracted mandibular first molars, with curved mesiobuccal canals (10–20°) and independent foramina, were distributed across 5 experimental groups (n=15 each) according to the instrumentation system used. Roots were secured in Eppendorf tubes, the canals were irrigated with double-distilled water, and the instrumentation time was recorded. After instrumentation, the roots were removed from the Eppendorf tubes and the amount of extruded debris was calculated by subtracting the initial weight from the final weight. The assumption of normality was rejected by the Shapiro–Wilk test, followed by the Kruskal–Wallis test with a post-hoc Dunn's test. A simple linear regression analysis was run to test for correlation between amount of extruded debris and time required for instrumentation.*
Results: *The PTN and HCM systems were associated with significantly (p<0.05) greater amounts of extruded debris and longer instrumentation time (PTN and HCM>HEDM, WOG, RCB). There was no significant difference between the PTN and HCM groups (p>0.05), nor between the HEDM, WOG, and RCB groups (p>0.05). Simple linear regression demonstrated a positive correlation (r=0.74, p<0.05) between the amount of debris extruded and instrumentation time.*
Conclusions: *The RCB, WOG, and HEDM systems were associated with less debris extrusion and shorter instrumentation time when compared to the PTN and HCM systems.*

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Introduction

During root canal preparation, apical extrusion of debris, irrigants, and/or bacteria can occur, potentially leading to such complications as post-operative pain, flare-ups, or even treatment failure (1, 2). Apical extrusion has been reported as the main cause of pain after completion of endodontic treatment (3). Which factors increase the amount of extruded debris remains controversial; studies have demonstrated associations with the type of file motion, type of irrigant, working length, cross-section, tip, taper, flexibility, heat treatment, and number of files used (4-7).

Advances in metallurgy and kinematics have reduced the number of instruments needed instrument a root canal system (8). However, the literature clearly shows that all systems in use, however advanced, lead to apical extrusion of debris. It is thus important to investigate the amount of debris extruded and the factors associated with this reduction or increase (9-11). Instrumentation time is another important factor, as several systems (whether reciprocating or rotary) are based on a "single-file" philosophy for canal preparation and previous work has shown that a shorter file activity time within the canal system can generate less debris extrusion (12, 13).

Within this context, the objective of this study was to compare canal preparation time and apical extrusion of debris during instrumentation with the ProTaper Next (PTN), HyFlex CM (HCM), HyFlex EDM (HEDM), WaveOne Gold (WOG), and Reciproc Blue (RCB) systems. The null hypothesis is that there would be no difference in the amount of extruded debris or the time required to perform instrumentation across these different systems.

Materials and Methods

Specimen selection and preparation

Once approval from the local Research Ethics Committee had been obtained (opinion no. 2,379,268), 75 mandibular first molars which had been extracted for various reasons were included in the present study. Teeth with fully formed roots showing independent foramina, curvature angles of 10-20° (14), absence of calcifications, resorption, or previous endodontic treatment, and with an initial apical canal diameter corresponding to that of a #15 K-file (Maillefer Corp, Ballaigues, Switzerland) were selected and disinfected by soaking in 0.5% chloramine-T trihydrate solution for one week.

Sample size calculation was performed in G*Power 3.1.9.4 software, The amount of debris extruded was considered the primary outcome of interest. Based on prior work by Uslu et al. (15), to detect a difference of 0.0024 between groups, with a standard error of 0.0025, statistical power of 0.80, and an alpha level of 0.05, a sample size of 15 specimens per group would be required.

All tooth crowns were sectioned at the cementoenamel junction with a diamond disc (Horico Dental Hpf; Ringleb, Berlin, Germany) coupled to a slow-speed handpiece powered by a micromotor, under constant refrigeration, to generate specimens 13 mm in length, as confirmed by a digital caliper (500 series, DIN 862; Mitutoyo, São Paulo, SP, Brazil). The initial diameter of the mesiobuccal canal was established by advancement of a #15 K-file (Dentsply Maillefer, Ballaigues, Switzerland) until it fit snugly within the canal and its tip was just visible in the apical foramen under an operating microscope at 12.5x magnification (Stemi 508; Carl Zeiss, Jena, Germany). The same procedure was used to determine the working lengths of the specimens. Canals that did not meet this criterion were excluded from the study and replaced with new specimens. Two #10 K-files were introduced into each mesial root canal, in a clockwise/counterclockwise motion with slight apical pressure, to confirm the presence of independent foramina under 8x magnification (Stemi 508; Carl Zeiss, Jena, Germany).

Group allocation

Specimens were randomly allocated (www.random.org) across 5 groups (n=15 each) depending on the system used for instrumentation of the mesiobuccal canals.

The mesiolingual canals were not exposed to any type of instrumentation or irrigation at any point in the experiment.

Instrumentation of sample groups
PTN group: an X1 (17.04) PTN file (Dentsply Maillefer, Ballaigues, Switzerland) was used in rotary motion (300 rpm, 2 N·cm). Three in-and-out movements (pecks), with a stroke amplitude of 3 mm, were performed in each third of the canal (cervical, middle, and apical) until the WL was reached (1 mm short of the apical foramen). The exact same sequence was then followed with an X2 (25.06) instrument.
HCM group: the 25.08 instrument (500 rpm; 2.5 N·cm) of the Hyflex CM – Controlled Memory System (Coltène, Altstätten, Switzerland) was used to prepare the cervical third. The canal was then instrumented in sequence with the 20.04, 25.04, 20.06, and 25.06 instruments, using the same speed and torque settings, the same type and amplitude of motion, and the same WL determined for the PTN group.
HEDM group: the OneFile instrument (25/~, variable taper) of the Hyflex EDM rotary system (Coltène, Altstätten, Switzerland) was used, again employing the same speed and torque (500 rpm, 2.5 N·cm), type and amplitude of motion, and WL used for the X1 instrument of the PTN group.
RCB group: an R25 (25.08) RCB file (VDW, Ballaigues, Switzerland) was used in reciprocating motion. Three in-and-out movements (pecks) with a stroke amplitude of 3 mm were performed in each third of the canal (cervical, middle, and apical) until the WL was reached (1 mm short of the apical foramen).
WOG group The primary instrument of the WOG system (25.07) was used in a manner similar to that described for the RCB group.
Instrumentation of the respective experimental groups was performed with the aid of an X-Smart Plus motor (Dentsply Maillefer, Ballaigues, Switzerland), adjusted for each system, always by the same operator. Regardless of system, each file was used only once, for the preparation of only one canal, and later discarded.
Throughout instrumentation, the specimens were irrigated with 3 mL of double-distilled water per root third, through a 30G NaviTip needle (Ultradent Products Inc, South Jordan, UT). In all groups, after each cycle of instrumentation and irrigation, foramen patency was controlled with a #10 K-file advanced 1 mm beyond the foramen. At the end of the instrumentation, a final irrigation with 1 mL of the same irrigant used throughout was performed, never exceeding the total amount of irrigant standardized for all specimens (10 mL). Canals were evacuated with the aid of capillary tips (Ultradent, South Jordan, UT) and further dried with the paper points provided with the respective systems.

Fabrication of devices for collection and weighing of extruded debris
This study followed the methodological parameters proposed by Myers and Montgomery (16) and modified by other authors (7, 17) to quantify the amount of debris extruded through the apical foramen after instrumentation. The initial weight of each Eppendorf tube (Eppendorf do Brasil, São Paulo, SP, Brazil) was determined by weighing three consecutive times on a precision balance (Ohaus Corporation, Parsippany, NJ, USA) with a resolution of 10^{-5} g. The tip of a #2 hand plugger (SS White Artigos Dentários Ltda, Rio de Janeiro, Brazil) was heated and used to puncture a hole in the stopper of each Eppendorf tube. The root was pushed through this hole and a rubber dam (Madeitex, São Paulo, SP, Brazil) was placed for isolation, simulating a clinical procedure. To equalize inner and outer air pressure levels, a 27G short disposable anesthetic needle (Unoject DFL Ltda, Rio de Janeiro, RJ, Brazil) was inserted through the rubber dam and stopper. Each Eppendorf/root assembly was then placed into an opaque vial to prevent the operator from having any visual contact with the inside of the tubes. Instrumentation was then performed, and any apically extruded debris was thus collected inside the Eppendorf tube.
To collect any residual debris still adher-

ent to the outer root surface, 1 mL of double-distilled water in a 10 mL hypodermic syringe (BD Plastipak, Curitiba, Brazil) was used to rinse the root; any debris thus removed was caught in the Eppendorf tube. In order to allow complete evaporation of water from the Eppendorf tubes and subsequent weighing of the extruded debris, the tubes incubated for 5 consecutive days at a constant temperature of 70 °C (Model EL-14, Odontobrás, São Paulo, Brazil). In all experimental groups, each Eppendorf tube was weighed in triplicate after instrumentation, using the same procedure described above. The mean of the three weights was recorded as the final value. The weight of the extruded debris in grams was obtained by subtracting the mean final weight from the mean initial weight of each Eppendorf tube.

Assessment of overall instrumentation time

The entire instrumentation sequence was timed (Seiko, Japan). The timer was started only when the instrument was activated and introduced into the channel and stopped whenever the instrument was removed, thus yielding the actual instrumentation time.

Statistical analysis

Data on debris weight and instrumentation time were entered into BioEstat 5.0 for analysis. The Shapiro-Wilk test rejected the assumption of normality for both outcomes of interest (amount of extruded debris and instrumentation time).

Descriptive analyses were performed. The nonparametric Kruskal-Wallis test (with Dunn's post-hoc test) was used, at a significance level of 5%.

A simple linear regression analysis was run in Minitab (version 16) to test for correlation between amount of extruded debris and time required for instrumentation.

Results

Figure 1 represents the amount of debris extruded and the actual instrumentation time (in seconds) for all groups. The systems associated with the greatest amount of extrusion were PTN and HCM, with both yielding significantly more debris ($p<0.05$) than the HEDM, WOG, and RCB systems (Figure 1A). There was no significant difference between the PTN and HCM groups ($p>0.05$), nor between the HEDM, WOG, and RCB groups ($p>0.05$).

Regarding instrumentation time, the HCM and PTN systems were associated with significantly longer time ($p<0.05$) than the HEDM, RCB, or WOG systems (Figure 1B). Again, there was no significant difference between the HCM and PTN groups ($p>0.05$), nor between the HEDM, WOG, and RCB groups ($p>0.05$).

Simple linear regression analysis demonstrated a positive correlation ($r=0.746$, $p<0.05$) between the amount of debris extruded and instrumentation time (Figure 2).

Discussion

The null hypothesis was rejected, as there were significant differences both in the amount of extruded debris and in the time required for instrumentation across the systems compared herein.

The inclusion criteria of this study are factors that ordinarily have an influence on the amount of debris extruded. The experiment was performed on mesial roots of mandibular molars because curved roots are usually associated with a greater amount of debris extrusion when compared to straight roots, mainly due to the challenging preparation of the former (18). Teeth with a single root canal are widely used in such research because both instrumentation and debris collection are easier; however, this practice can skew the results, because the canals of these teeth are very wide. Conversely, molars have narrow, curved root canals, generating more debris extrusion and thus making the results of the study closer to the experience of everyday clinical practice (19). It is important to note that all root lengths were standardized at 13 mm, avoiding any influence of canal length on instrumentation time or amount of debris extruded. Controversy remains as to whether variation in working length can lead to changes in the amount of debris extruded. However, as assessing this was not within the scope of the pres-

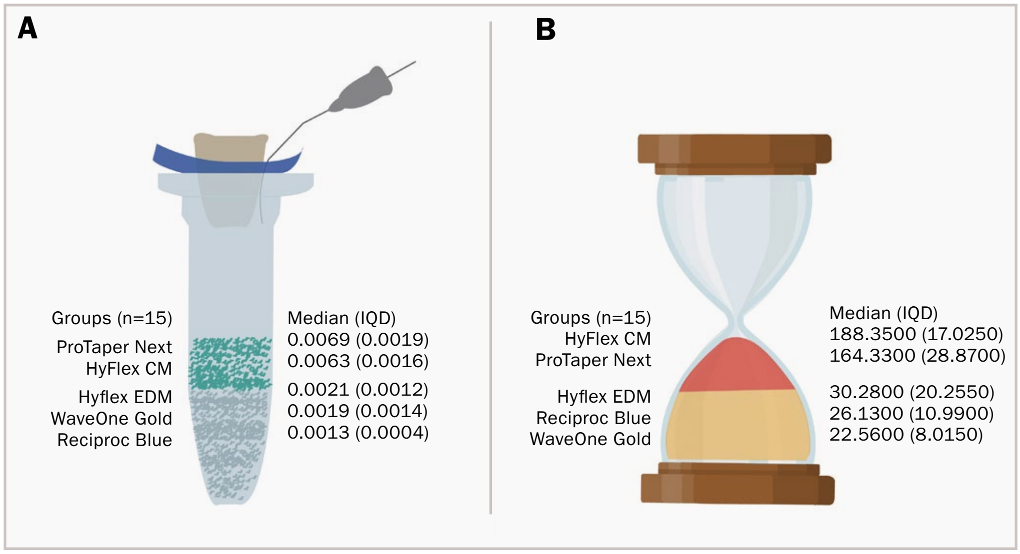

Figure 1. Amount of debris extruded during instrumentation with each system **(1A)**. Time (in seconds) required to perform instrumentation with each system **(1B)**. Different colors denote statistically significant differences (p<0.05). IQR, interquartile range n=15 per group.

ent study, the working length was established at 1 mm short of the apex for all groups (8, 20, 21).

Double-distilled water was chosen as the irrigant because any extravasation that occurs during instrumentation will evaporate completely while the Eppendorf cubes are incubated, without leaving any residue that might interfere with weighing, as sodium hypochlorite or chlorhexidine would (22).

The study followed the method proposed by Myers and Montgomery (16) for collection and weighing of debris extruded through the apical foramen, a widely cited protocol that is extensively represented in the existing literature (6, 22-24). However, we did modify the Myers and Montgomery method on the basis of recent work (7, 17, 18). In addition, the Eppendorf tubes were placed into opaque vials with a diameter similar to that of the tube itself, thus ensuring that only the root canal access opening was visible during instrumentation. This not only ensured blinding of the operator but also made the conditions of the experiment closer to those of clinical

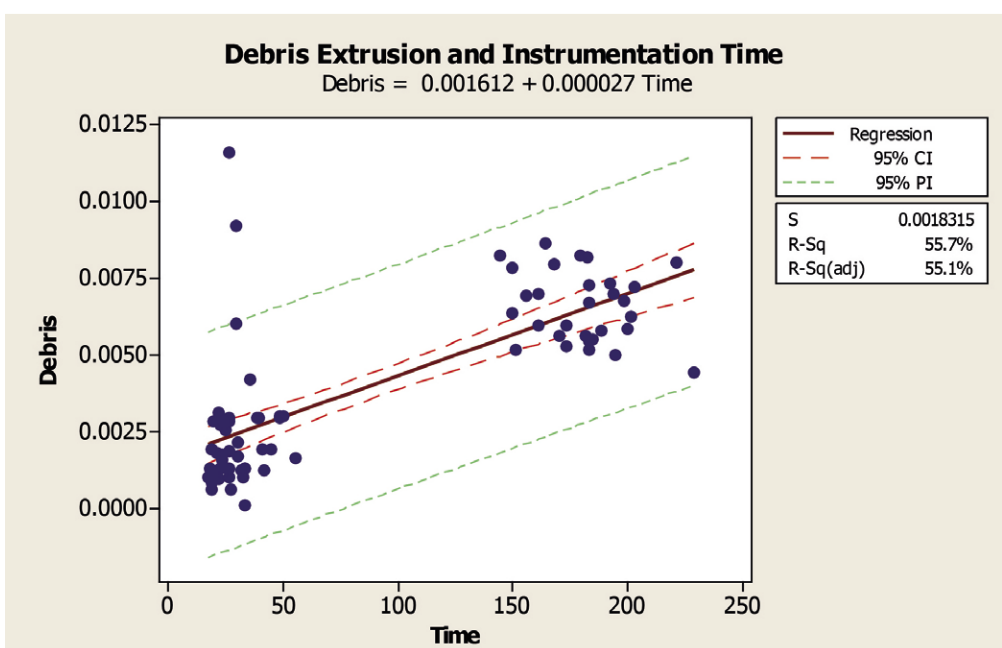

Figure 2. Association between amount of debris extruded and the required instrumentation time. Statistically significant on linear regression analysis (p<0.05).

practice and prevented handling of the Eppendorf tube by the operator, which might have influenced the final weight of the specimens.

The systems associated with the most debris extrusion were those that required longer instrumentation times, indicating a possible correlation - as demonstrated by simple linear regression - that the longer the instrumentation time, the greater the amount of debris extruded. This corroborates the previous findings of Karatas et al. (12). Likewise, Dincer et al. (5) demonstrated that the PTN system extruded more debris and required longer instrumentation times compared to the WOG system, as did Ehsani et al. (25), who observed greater extrusion of debris with those systems in which instrumentation took longer. The authors believe this might be explained because using a greater number of files naturally requires a longer instrumentation time, which means more time spent cutting dentin and, consequently, greater formation of debris, which may eventually be extruded through the apex. Thus, when working with this type of system, the use of irrigation protocols capable of removing debris from the canal and isthmus is paramount (26).

Reciprocating instruments extruded less debris when compared to rotary systems with multiple files, as in other studies (17, 19, 27). This may explain the finding of a recent systematic review by Martins et al. (3) that reciprocating systems are associated with less postoperative pain when compared to rotary systems. However, when the reciprocating systems included in this study were compared to the HEDM system (which, although rotary, is also a single-file system), the amount of extruded debris was found to be similar.

Gummadi et al. (28) observed greater debris extrusion with the WaveOne system when compared to the One Shape single-file rotary system; however, they analyzed the first generation of this reciprocating system, while the present study used the later WaveOne Gold iteration.

The findings of this experiment demonstrate that instrumentation kinematics play a relevant role the amount of debris extruded, but that even rotary systems which employ a single file to simplify preparation reduce the risk of debris extrusion compared to multiple-file systems. This can be explained by the fact that using a greater number of instruments can generate a greater amount of debris. (17, 29)

Our findings contradict those of previous studies (15, 30, 31) that reported greater extrusion of reciprocating instruments, probably due to differences in instrumentation protocol. When reciprocating preparation is done by thirds, alternating with glide path maneuvers - which have been proven to lead to less debris extrusion (10) - and combined with abundant irrigation, these instruments are probably associated with a similar or even reduced amount of extrusion compared to rotary systems.

Despite being mentioned by other authors such as Frota et al. (20) and Amaral et al. (1) as a possible interfering factor in the extrusion of debris, instrument taper was not relevant in the present study. In our experiment, #25 rotary instruments but with smaller tapers generated more debris than reciprocating instruments with the same diameter but a relatively larger taper, a finding also reported by Dincer et al. (5).

The systems evaluated in this study all have different cross-sections, but again, this was not a determining factor in the amount of debris extrusion observed. The literature on the matter is controversial (25, 30, 32). The RCB instrument, which has an S-shaped section with two sharp cutting edges, was not associated with greater debris extrusion than the WOG system, which has a parallelogram-shaped cross-section with alternating points of contact. Although the initial file of the HEDM rotary system has a unique variable cross-section design along the active cutting shaft, this was not associated with any difference in the amount of debris extruded as compared to other single-file systems.

Another important point is the difference in heat treatment of the tested instruments. Among the rotary systems analyzed, PTN uses an M-Wire alloy, while the HCM system employs a memory NiTi wire and would thus theoretically be capable of greater canal-centering ability, with less

deviation, thus allowing more conservative preparations (33). Nevertheless, this potential advantage was not associated with any difference in the amount of debris extruded through the apical foramen of curved canals between the two systems. The HEDM rotary instrument, which is manufactured using the electric discharge machining (EDM) heat treatment, was associated with a smaller amount of debris extrusion compared to the other rotary systems evaluated; however, this result may be attributable more to the fact that the system allows preparation of the entire canal with one instrument (single-file endodontics) (34).
The reciprocating systems all achieved similar results in terms of debris extrusion, regardless of their unique heat treatments and cross-section designs. The greater flexibility of these systems is probably associated with greater canal-centering ability, but has no bearing on the amount of debris extruded through the apical foramen.

Conclusions

Within the limitations of this study, we conclude that debris extrusion occurred with all systems. The RCB, WOG, and HEDM systems were associated with less debris extrusion and shorter instrumentation time when compared to the PTN and HCM systems.

Clinical Relevance

Apical extrusion has been reported as the main cause of pain after endodontic treatment.

Conflict of Interest

The authors deny any conflict of interest.

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References

1. *Amaral AP, Limongi PBOC, Fontana CE, et al. Debris Apically Extruded by Two Reciprocating Systems: A Comparative Quantitative Study. Eur J Dent 2019;13:625-8.*
2. *Tavares SG, Fontana CE, Martin AS De, et al. In Vivo Evaluation of Painful Symptomatology after Endodontic Treatment Performed Using Two Different Irrigation Needle Insertion Depths. Eur J Dent 2020;14:274-280.*
3. *Martins CM, Batista VE, Souza AC, et al. Reciprocating kinematics leads to lower incidences of postoperative pain than rotary kinematics after endodontic treatment: A systematic review and meta-analysis of randomized controlled trial. J Conserv Dent 2019;22:320-331.*
4. *Silva EJNL, Teixeira JM, Kudsi N, et al. Influence of apical preparation size and working length on debris extrusion. Braz Dent J 2016;27:28-31.*
5. *Dincer A, Guneser M, Arslan D. Apical extrusion of debris during root canal preparation using a novel nickel-titanium file system: WaveOne gold. J Conserv Dent 2017;20:322-5.*
6. *Sen OG, Bilgin B, Kocak S, et al. Evaluation of Apically Extruded Debris Using Continuous Rotation, Reciprocation, or Adaptive Motion. Braz Dent J 2018;29:245-8.*
7. *Boijink D, Costa DD, Hoppe CB, et al. Apically Extruded Debris in Curved Root Canals Using the WaveOne Gold Reciprocating and Twisted File Adaptive Systems. J Endod 2018;44:1289-1292.*
8. *Mendonça de Moura JD, Bueno CE da S, Fontana CE, Pelegrine RA. Extrusion of Debris from Curved Root Canals Instrumented up to Different Working Lengths Using Different Reciprocating Systems. J Endod 2019;45:930-4.*
9. *Pedrinha VF, Brandão JM da S, Pessoa OF, Rodrigues P de A. Influence of File Motion on Shaping, Apical Debris Extrusion and Dentinal Defects: A Critical Review. Open Dent J 2018;12:189-201.*
10. *Plotino G, Nagendrababu V, Bukiet F, et al. Influence of Negotiation, Glide Path, and Preflaring Procedures on Root Canal Shaping - Terminology, Basic Concepts, and a Systematic Review. J Endod 2020;46:707-729.*
11. *Ahn SY, Kim HC, Kim E. Kinematic effects of nickel-titanium instruments with reciprocating or continuous rotation motion: A systematic review of in vitro studies. J Endod 2016;42:1009-1017.*
12. *Karataş E, Ersoy İ, Gündüz HA, et al. Influence of Instruments Used in Root Canal Preparation on Amount of Apically Extruded Debris. Artif Organs 2016;40:774-7.*
13. *Li H, Zhang C, Li Q, et al. Comparison of cleaning efficiency and deformation characteristics of Twisted File and ProTaper rotary instruments. Eur J Dent 2014;8:191-6.*
14. *Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol 1971;32:271-5.*
15. *Uslu G, Özyürek T, Yılmaz K, et al. Apically Extruded Debris during Root Canal Instrumentation with Reciproc Blue, HyFlex EDM, and XP-endo Shaper Nickel-titanium Files. J Endod 2018;44:856-9.*
16. *Myers GL, Montgomery S. A comparison of weights of debris extruded apically by conventional filing*

and Canal Master techniques. J Endod 1991; 17:275-9.
17. Silva EJ, Carapia MF, Lopes RM, et al. Comparison of apically extruded debris after large apical preparations by full-sequence rotary and single-file reciprocating systems. Int Endod J 2016;49:700-5.
18. Karataslioglu E, Arslan H, Er G, Avci E. Influence of canal curvature on the amount of apically extruded debris determined by using three-dimensional determination method. Aust Endod J 2019;45:216-224.
19. De-Deus G, Neves A, Silva EJ, et al. Apically extruded dentin debris by reciprocating single-file and multi-file rotary system. Clin Oral Investig 2015;19:357-361.
20. Frota MMA, Bernardes RA, Vivan RR, et al. Debris extrusion and foraminal deformation produced by reciprocating instruments made of thermally treated NiTi wires. J Appl Oral Sci 2018;26:1-8.
21. Silva EJ, Teixeira JM, Kudsi N, et al. Influence of Apical Preparation Size and Working Length on Debris Extrusion. In: Braz Dent J 2016;27:28-31.
22. Silveira C, Pimpão MV, Fernandes LA, et al. Influence of different irrigation solutions and instrumentation techniques on the amount of apically extruded debris. Eur Endod J 2019;4:122-6.
23. Caviedes-Bucheli J, Castellanos F, Vasquez N, et al. 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;49:255-270.
24. Doğanay Yıldız E, Arslan H. The effect of blue thermal treatment on endodontic instruments and apical debris extrusion during retreatment procedures. Int Endod J 2019;52:1629-1634.
25. Ehsani M, Farhang R, Harandi A, et al. Comparison of Apical Extrusion of Debris by Using Single-File, Full-Sequence Rotary and Reciprocating Systems. J Dent 2016;13:394-9.
26. Duque JA, Duarte MAH, Canali LCF, et al. Comparative Effectiveness of New Mechanical Irrigant Agitating Devices for Debris Removal from the Canal and Isthmus of Mesial Roots of Mandibular Molars. J Endod 2017;43:326-331.
27. Lu Y, Chen M, Qiao F, Wu L. Comparison of apical and coronal extrusions using reciprocating and rotary instrumentation systems. BMC Oral Health 2015;15:92.
28. Gummadi A, Panchajanya S, Ashwathnarayana S, et al. Apical extrusion of debris following the use of single-file rotary/reciprocating systems, combined with syringe or ultrasonically-facilitated canal irrigation. J Conserv Dent 2019;22:351-5.
29. Ehsani M, Farhang R, Harandi A, et al. Comparison of Apical Extrusion of Debris by Using Single-File, Full-Sequence Rotary and Reciprocating Systems. J Dent 2016;13:394-9.
30. Labbaf H, Moghadam KN, Shahab S, et al. An in vitro comparison of apically extruded debris using reciproc, protaper universal, neolix and hyflex in curved canals. Iran Endod J 2017;12:307-311.
31. Delvarani A, Mohammadzadeh Akhlaghi N, Aminirad R, et al. In vitro Comparison of Apical Debris Extrusion Using Rotary and Reciprocating Systems in Severely Curved Root Canals. Iran Endod J 2017;12:34-7.
32. Vivekanandhan P, Subbiya A, Mitthra S, Karthick A. Comparison of apical debris extrusion of two rotary systems and one reciprocating system. J Conserv Dent 2016;19:245-9.
33. Razcha C, Zacharopoulos A, Anestis D, et al. Micro-Computed Tomographic Evaluation of Canal Transportation and Centering Ability of 4 Heat-Treated Nickel-Titanium Systems. J Endod 2020;46:675-681.
34. Pedullà E, Lo Savio F, Boninelli S, et al. Torsional and Cyclic Fatigue Resistance of a New Nickel-Titanium Instrument Manufactured by Electrical Discharge Machining. J Endod 2016;42:156-9.