Exploration of Medicine

Open Exploration

Open Access Original Article

A comparison of the apical extrusion of debris by tapering in rotary systems: in vitro experimental study

Eshaghali Saberi[1], Shima Bijari[2], Farshid Gholami[1], Ebrahim Mohtashami[1], Forough Farahi[1]*

[1]Department of Endodontics, School of Dentistry, Oral and Dental Disease Research Center, Zahedan University of Medical Sciences, Zahedan 9817699693, Iran

[2]Department of Endodontics, School of Dentistry, Birjand University of Medical Sciences, Birjand 9717434765, Iran

***Correspondence:** Forough Farahi, Department of Endodontics, School of Dentistry, Oral and Dental Disease Research Center, Zahedan University of Medical Sciences, Zahedan 9817699693, Iran. Foroughfarahi879@gmail.com

Academic Editor: Gaetano Isola, University of Catania, Italy

Received: December 6, 2024 **Accepted:** June 4, 2025 **Published:** August 19, 2025

Cite this article: Saberi E, Bijari S, Gholami F, Mohtashami E, Farahi F. A comparison of the apical extrusion of debris by tapering in rotary systems: in vitro experimental study. Explor Med. 2025;6:1001351. https://doi.org/10.37349/emed.2025.1001351

Abstract

Aim: Apical extrusion of debris during root canal preparation can lead to inflammation, flare-ups, and delayed recovery. Therefore, instrumentation techniques that minimize debris extrusion are crucial. This study aimed to compare the apical extrusion of debris by four single-file, full-sequence rotary systems with different tapers.

Methods: In this in vitro study, 68 human maxillary lateral incisor teeth with identical root lengths and canal curvatures of less than 10 degrees were used. The teeth were randomly assigned to four experimental groups (n = 17) based on the instrument type: One-Shaped (25, 0.06), 2-Shaped (25, 0.04), Hyflex (25, 0.08), and Neoniti A1 (25, 0.08). Canal preparation was performed according to the manufacturer's instructions for each file. Extruded debris was collected in pre-weighed vials, and after drying in an incubator, the amount of debris was determined by measuring the weight difference of the vials before and after preparation. Data were analyzed using SPSS 20, with a one-way analysis of covariance (ANOVA) and Tukey's post hoc test at a significance level of 0.05.

Results: The amount of extruded debris in the One-Shaped file was significantly higher than the extruded debris amount in Neoniti A1 (p = 0.049), Hyfex (p = 0.013), and the 2-Shaped file (p = 0.003).

Conclusions: The null hypothesis was not invalidated due to significant differences in debris extrusion between the instruments observed in the present investigation. Within the limitations of the present study, the One-Shaped file was associated with higher debris extrusion due to the taper design and other system-specific characteristics. Clinical studies are required to assess whether these findings have an impact on the clinical outcome.

Keywords

Endodontics, root canal preparation, dental pulp cavity

Introduction

Successful endodontic treatment depends on thorough chemomechanical preparation of the root canal system, which aims to eliminate bacteria and necrotic tissue [1]. During this preparation process, dentinal debris and pulpal tissue, which may contain microorganisms, can be irrigated and enter the periradicular tissues [2, 3]. These substances can cause inflammation and flare-ups and compromise treatment outcomes [4]. Flare-ups characterized by pain and/or swelling can occur in 1.5% to 5.5% of root canal treatments and may increase to 50% during or a few days after treatment, often leading to unscheduled visits [5, 6]. Consequently, minimizing apical extrusion is a critical objective in endodontic instrumentation.

At present, all canal preparation methods are associated with the extrusion of infectious debris into periapical tissues, but the amount of extruded infectious debris varies by the preparation techniques and file design [7, 8]. Rotary nickel-titanium (NiTi) instruments have revolutionized endodontic practice, offering enhanced efficiency and predictability compared to traditional hand instrumentation [9]. These systems employ various design features, including different tapering profiles, which influence their cutting efficiency and debris management [10]. Tapering, the gradual increase in instrument diameter from the tip to the shaft, plays a crucial role in shaping the root canal and facilitating debris removal. In 2008, a new rotary instrumentation technique was introduced in which, instead of using sequence files, it used a single file to shape the canal [11], claiming that these single-file systems caused an improvement in shaping and had a lower debris extrusion rate [12]. Today, various commercial single-file systems are available with different tapering, including Hyflex (Coltène/Whaledent, Altstätten, Switzerland) and Neonit A1 (NEOLIX, Châtres-la-Forêt, France) with 0.08 tapering that is made with CM-wire technology; a feature that enables us to control material memory, flexibility, and high resistance to cyclic fatigue [13]. One-Shaped file (Micro-Mega, Besançon, France) with 0.06 tapering has a triangular cross-section in the apical area and two cutting edges in the coronal region, and this gradual change from apical to coronal leads to its optimal cutting performance [14]. The 2-Shaped file (Micro-Mega, Besançon, France) is made with T-wire technology and has 0.04 tapering and an asymmetric cross section, and its high flexibility leads to optimal negotiation of the canal curvatures [15]. The influence of varying taper designs on apical debris extrusion remains a subject of ongoing investigation, and previous studies reported different results. In one study, after comparing the amount of extruded apical debris by single-file systems, no significant difference was observed between the Reciproc system [the R25 instruments (VDW, Munich, Germany)] and a medium Wave One instrument (Dentsply, Maillefer, Ballaigues, Switzerland) [16]. While in another study, the Wave One Gold system (WOG; Dentsply Maillefer, Ballaigues, Switzerland) showed a lower average value of apically extruded debris compared to the Neoniti A1 system (Neolix, Châtres-la-Forêt, France) [17]. On the other hand, one of the prerequisites to prevent post-treatment flare-ups is the reduction of extruded apical debris. The preparation process is simplified by preparing the channel with only one file instead of using multiple file systems [12]. In addition, the suggestion for using these files exclusively is advantageous in reducing cyclic fatigue, file breakage, work time, cost, and cross-contamination among patients, which is a common problem with sequential files [18–20].

Given the increasing trend of using rotary systems and the unique advantages of using single-file systems in improving root canal treatment results compared to multi-file systems, especially on apical debris extrusion, this study evaluated different rotary single files in vitro to assess their effectiveness in minimizing apical debris extrusion. We quantified and compared apical debris extrusion by focusing on four common tapering designs in single-file NiTi rotary systems (One-Shaped, 2-Shaped, Hyflex, and Neoniti A1) to determine the optimal treatment option for reducing debris in the periapical region. The null hypothesis was that there is no difference between these file systems in the apical extrusion of debris.

Materials and methods

Study design and statistical population

In this in vitro experimental study, using a simple random sampling method, 68 single-canal teeth extracted due to periodontitis or orthodontic reasons in the Surgery Department of the Dentistry School of Zahedan University of Medical Sciences in 2020 were selected.

Sample size and sampling

Considering the mean and variance of the amount of apical debris extrusion in different conditions in previous studies [21, 22], and considering α = 0.05 and β = 0.2, and using the following equation, the sample size was estimated to be 17 teeth in each group.

$$n = \frac{\left[Z_{1-\alpha/2} + Z_{1-\beta}\right]^2 \times \left(S_1^2 + S_2^2\right)}{d^2} = \frac{5648}{18^2} \approx 17$$

Inclusion and exclusion criteria

Eligible teeth had closed apices, a single root canal, a length of approximately 15 mm, a canal curvature of less than 10 degrees, and no caries, restorations, resorption, previous endodontic treatment, or signs of infection. Teeth with cracks and dentinal defects were excluded after examination by a dental operating microscope (OPMI Pico, Carl Zeiss, Göttingen, Germany) under × 20 magnification.

Random allocation

To balance the number of samples allocated to each of the study groups, the selected teeth were randomly divided into four experimental groups (n = 17 each) using a randomized block sampling method. For random allocation, 17 blocks were created using Excel software, with each block containing one sample from each group (A: One-Shaped, B: 2-Shaped, C: Hyflex, D: Neoniti A1). At each stage, a random block was selected to allocate the teeth into one of the four groups. This process continued until the sample size was completed.

Teeth preparation and root canal shaping

The eligible teeth were stored in 0.5% chloramine T solution for 48 hours, followed by storage in distilled water at 4°C. After cleaning and debridement with a periodontal scaler, the crowns were sectioned to a length of 15 mm. The working length (WL) was established 1 mm short of the apical foramen using a #10 K-file (Mani, Tochigi, Japan). Radiographs were taken from the buccal and proximal views to confirm the WL and assess the degree of canal curvature using Schneider's method [23].

Root canal preparation was performed by an experienced operator using a rotary motor (VDW Silver, Munich, Germany) according to the manufacturer's recommendations. The apical preparation size for all groups was set to #25. Canals were irrigated with 5 mL of double-distilled water during preparation, and 1 mL of water was used as the final irritant, with the irrigation needle inserted 1 mm from the WL.

The standard access cavity was prepared by a diamond fissure bur (Diatech, Coltene Whaledent, Altstetten, Switzerland) with a high-speed handpiece under air-water spray cooling. The crowns were sectioned such that all specimens had a length of 15 mm from the root apex. A stainless-steel #10 K-file (Mani, Tochigi, Japan) was inserted into the canals for established apical patency. The file with a rubber stopper was carefully introduced into each canal until it was just visible at the apical foramen. The WL of all teeth was established as 1 mm short of this measurement. A #15 K-file was inserted into the WL of the canal, and teeth that had a snug fit in their WL were selected, so the initial diameter of the apical foramen was similar and the size of #15 K-file (Mani, Tochigi, Japan). The teeth were radiographed by digital radiography (EZ Sensor; Vatech, Hwaseong, Republic of Korea) from the buccal and proximal view to confirm the WL, one canal, a single foramen apical, and determine the degree of canal curvature. Teeth with a curvature of fewer than 10 degrees were selected according to Schneider's method [23].

Root canal preparation

The process of cleaning and shaping was done by an experienced operator. The apical preparation size of all canals was #25, and all preparations were done with a Silver Reciproc electric motor (VDW, Munich, Germany). During each instrument, canals were irrigated with 5 mL of double-distilled water with a side-vented needle syringe (0.3 × 25 mm, Endo-Top, Cerkamed, Stalowa Wola, Poland), and 1 mL of water was used as the final irritant. The irrigation needle was inserted within 1 mm of the WL by using slight hand vibration and up-and-down motion.

No glide path was created because the initial size of all the canals was equal to the #15 K-file. Each single-file instrument was used for only three canals, and all instruments were used following their manufacturers' recommendations. After using each instrument, they were cleaned with damp gauze, and the time to use each file was the same after reaching the WL. The instrumentation was performed as follows.

Instrumentation protocol

- Group A (One-Shaped): 25/0.06, 400 rpm, 4 Ncm torque.
- Group B (2-Shaped): 25/0.04, 300 rpm, 2 Ncm torque.
- Group C (Hyflex EDM): 25/0.08, 500 rpm, 2.5 Ncm torque.
- Group D (Neoniti A1): 25/0.08, 350 rpm, 1.5 Ncm torque.

Each instrument was used in only three canals, and all instruments were cleaned with damp gauze after use to prevent contamination. The same time duration was maintained for each file.

Collection of extruded debris

In this study, Eppendorf tubes (Eppendorf India, Chennai, India) were used to collect debris according to the Myers and Montgomery method [24]. Initially, the initial weight of each tube without a stopper was measured 3 times by electronic analytical balance (Sartorius AG, Göettingen, Germany) with an accuracy of 10^{-4} g, and their mean was considered as the initial weight of the tube. To prevent the effect of dust and glove powder on the weight of the tubes, the tubes were fixed on a penicillin vial, and metal foil was wrapped around them. A 27-gauge needle (Max-i-Probe, Dentsply-Rinn, Elgin) was inserted into the stopper to balance the air pressure inside and outside of the tube. After preparing the canals, the debris adhering to the root surface was washed and collected with 1 mL of distilled water. The tubes were incubated at 70°C for 5 days so that the irrigation fluid (distilled water) evaporated. The secondary mass of the tubes was measured 3 times by Electronic Balance, and their mean was calculated. Primary means were subtracted from the secondary means, and the mass of the apical debris extruded during preparation was calculated, and the resulting values were analyzed.

Statistical analysis

Data were analyzed using SPSS version 20 (SPSS, Chicago, IL, United States). One-way analysis of variance (ANOVA) was used to compare the groups, and Tukey's post hoc test was applied for pairwise comparisons, with a significance level set at $p < 0.05$.

Ethical consideration

The study was approved by the ethics committee of Zahedan University of Medical Sciences (IR.ZAUMS.REC.1398.061 on 2019-04-29). Informed consent was not required as the study utilized medical waste.

Results

Based on the study results, the amount of extruded debris in the One-Shaped file was significantly higher than in the other three files ($p = 0.006$) (Table 1).

A pairwise comparison of investigated files by Tukey's post hoc test showed that there is no significant difference between the amount of extruded debris in Neoniti A1, Hyflex, and 2-Shaped files. While the amount of extruded debris in the One-Shaped file was significantly higher than the extruded debris amount in Neoniti A1 ($p = 0.049$), Hyfex ($p = 0.013$), and the 2-Shaped file ($p = 0.003$) (Table 2).

Table 1. Amount of apically extruded debris (milligrams) by each rotary system (*n* = 17)

Study group	Debris extrusion, mean (SD)
One-Shaped group (*n* = 17)	0.0018 (0.00077)
2-Shaped group (*n* = 17)	0.0005 (0.00253)
Hyflex group (*n* = 17)	0.0010 (0.00074)
Neoniti A1 group (*n* = 17)	0.0013 (0.00082)
p-value*	0.006

SD: standard deviation; * one-way ANOVA; ANOVA: analysis of covariance

Table 2. Pairwise comparison of investigated files in terms of extruded debris

Pairwise comparison		Mean difference (I–J)	*p*-value
(I)	(J)		
Neoniti A1	Hyfex	0.00034	0.122
Neoniti A1	One-Shaped	–0.00048	0.049
Neoniti A1	2-Shaped	0.00084	0.306
Hyfex	One-Shaped	–0.00082	0.013
Hyfex	2-Shaped	0.00050	0.454
One-Shaped	2-Shaped	0.00132	0.003

Discussion

One of the most significant complications of apical extrusion is an interappointment flare-up, which is characterized by bone resorption, edema, and postoperative pain [25]. It was considered as root treatment failures, which is undesirable for both patients and dentists. The type of instrument is a significant factor that affects the amount of extruded debris [6, 26]. The findings of this study, which compared the apical extrusion of debris by four single-file, full-sequence rotaries with different tapering, indicated that different single-file instruments had different amounts of apical debris extrusion. The null hypothesis that there was no difference between the instrumentation systems was rejected. The One-Shaped file (0.06 taper) produced the most debris, while the Neoniti (0.08 taper), Hyflex (0.08 taper), and 2-Shape (0.04 taper) files showed significantly lower and comparable amounts. These results are consistent with previous studies indicating that all rotary systems—whether utilizing rotational motion, reciprocal motion, or manual techniques—can lead to extrusion [27–30]. Furthermore, these findings indicate that taper alone does not determine debris extrusion; other design features, including cross-section, pitch length, and helical angle, also play a role in this phenomenon [31, 32].

The Neoniti file, despite having a higher taper (0.08), extruded less debris compared to One-Shaped (0.06). This may be due to its variable pitch design, which reduces screwing effects and enhances coronal debris transportation. In contrast, One-Shaped has a constant pitch and helical angle, potentially facilitating more debris accumulation in the apical region [33]. It has been demonstrated that successful endodontic treatment can be achieved by properly handling engine-driven NiTi systems with enough antimicrobial irrigation [34]. Similarly, the Hyflex file demonstrated low debris extrusion, possibly due to its controlled memory (CM) NiTi alloy, which increases flexibility and reduces cutting aggressiveness [35].

Similar to the results of our study, Singbal et al. (2017) [31] showed that the amount of debris extrusion in the One-Shaped file was higher than in the Neoniti file. Based on the previous results, the One-Shaped file in comparison with other instruments (except Neoniti file), such as Wave One [32], other single file systems (Reciproc and F360), and the multi-file system (Mtwo, Reciproc file) [14], full sequence systems with rotational motions (Protaper universal) and reciprocation (Reciproc R25 and Wave One Primary) motions [36] did not show the advantage in the amount of extruded debris. The reason for these different results may be due to the variability in the type of compared instruments, the variability in the tapering of the files or the unique kinematic design of each file [37] such as pitch length, helical angle, cross-section and the rate of file contact with the canal walls and the speed used for each instrument. Endodontic files with a greater taper are thought to cause more apical debris extrusion because they remove more dentin during root canal preparation. The larger diameter and pronounced taper create more space for dentin chips and debris, which can then be pushed apically [3, 17, 38]. In the present study, this hypothesis was not proven because the One-Shaped file with 0.06 tapering had more debris extrusion than the Neoniti and Hyflex files with 0.08 tapering. Also, it is stated that the effect of pitch length and an increase in the variable pitches reduces the tendency to screw and also reduces the helical angle, hence causing a reduction in debris extrusion. On the other hand, the One-Shaped and Neoniti files had more debris extrusion compared to the other files in the study, though the taper of Neoniti (0.08) is higher than the One-Shaped (0.06), the presence of greater variable pitches in Neoniti, which forms between 2.25–6.00 mm of the file length, comparable to the constant pitch in One-Shaped, causes less debris extrusion in Neoniti [39].

Files with constant helical angles (like One-Shaped) increase the accumulation of debris, while varying helical angles enhance the removal of debris more efficiently. Neoniti files have a variable helical angle of 16 to 28 degrees from the tip [40]. On the other hand, the three-point contact of the blades at the tip of One-Shaped with the triangular cross-section will lead to more production of debris compared to the rounded tip of the Neoniti with the non-homothetic rectangular cross-section and its two-point contact [31].

The Neoniti and Hyflex systems are made of CM NiTi wires and by the thermal treatment process of conventional NiTi wires [35]. In the present study, the debris extrusion in Hyflex was less than that of Neoniti without a significant difference. Similar to our study, Labbaf et al. [41] in their study concluded that the amount of debris extrusion in the Hyflex is significantly less than in Neoniti. Unwinding of the spirals in the Hyflex file occurs during the instrumentation, this phenomenon may lead to a decrease in the cutting ability and consequently reduce the production of debris and its subsequent extrusion [41]. In another study that analyzed the amount of debris extrusion of the three Wave One Gold, RECIPROC Blue, and Hyflex EDM systems in 2020, Elashiry et al. [42] concluded that the highest amount of debris extrusion was for the Hyflex file. The reason for this difference can be attributed to the type of tooth studied.

Among all tested files, the 2-Shaped system (0.04 taper) exhibited the least debris extrusion. Its asymmetric cross-section reduces wall engagement and provides more space for coronal debris displacement [15, 43]. Furthermore, it operates at the lowest rotational speed (300 rpm), which may also contribute to reduced extrusion compared to higher-speed instruments like Hyflex (500 rpm) [42].

The speed used for each instrument was adjusted according to the manufacturer's instructions, and among the files, the highest and lowest speeds used were for Hyflex (500 rpm) and 2-Shaped (300 rpm) files. Similar to the results of this study, previous studies have shown that as the speed increases, the instrument-cutting efficiency increases [44, 45] and, consequently, the amount of debris extrusion may increase.

In this study, the type and amount of irritants were the same in all groups. Distilled water was used for irrigation instead of sodium hypochlorite to avoid sodium crystallization and an unwanted increase in weight of the extruded debris [14]. Curvature and the presence of more than one canal are among the factors that may affect the final extrusion of debris [46]. Hence, in the present study, to reduce the variables that may distort the results of the study, single-canal teeth were used that had a curvature of less than 10 degrees.

Overall, the amount of extruded debris in this study was not high, which can be attributed to the type of root used. The canal of the maxillary incisor teeth is single and wide, and can limit the pumping effects during file entry, and hence, debris extrusion decreases [47]. The WL was determined to be one millimeter shorter than the apical foramen and was confirmed by radiography. When the WL is considered up to the apical foramen or even passes it a bit, in comparison to when it is shorter for 1 mm, the amount of debris that is extruded increases [24, 48, 49].

This study had some limitations and strengths. The main limitations that affect the results generalization are: (a) despite calculating the ideal sample size, studies with larger sample size may provide more statistical power, (b) the nature of the study (in vitro), which does not fully replicate the dynamic environment of a clinical setting, where periapical tissues can act as natural barriers against debris extrusion [21], and (c) tooth selection was restricted to single-rooted teeth with < 10° curvature, which may not reflect more complex root canal anatomies encountered in clinical practice. Despite these limitations, the standardized methodology, including the use of consistent irrigation protocols, WL measurements, and instrument handling, minimized confounding variables. Additionally, four different tapering designs were analyzed, providing a broad comparison of debris extrusion patterns across various systems. The precision in measuring debris extrusion further enhanced the reliability of the findings.

Generally, the results of this study highlight that file design characteristics beyond tapering, such as cross-section and pitch variability, significantly impact debris extrusion levels. Therefore, dentists should consider all aspects of selected single files to minimize debris extrusion, improve root canal treatment outcomes, and help patients keep their natural teeth for longer periods, thereby postponing the need for dental replacements like implants. In addition, future research should explore the impact of torque and speed variations on extrusion rates, as well as conduct in vivo studies to confirm these findings under clinical conditions. Additionally, the role of different irrigation techniques in debris management should be further investigated.

In conclusion, the null hypothesis was not invalidated due to significant differences in debris extrusion between the instruments observed in the present investigation. Within the limitations of the present study, the One-Shaped file was associated with higher debris extrusion due to the taper design and other system-specific characteristics. Clinical studies are required to assess whether these findings have an impact on the clinical outcome.

Abbreviations

ANOVA: analysis of covariance

CM: controlled memory

NiTi: nickel-titanium

WL: working length

Declarations

Acknowledgments

The authors would like to thank the Vice-Chancellor for Research of Zahedan University of Medical Sciences for their support and cooperation.

Author contributions

ES: Conceptualization, Investigation, Data curation, Formal analysis, Writing—original draft, Writing—review & editing. SB: Conceptualization, Investigation, Writing—review & editing, Supervision. FG: Conceptualization, Investigation, Validation, Writing—review & editing, Supervision. EM and FF: Investigation, Writing—review & editing, Supervision. All authors read and approved the submitted version.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical approval

The study was conducted in accordance with the Declaration of Helsinki 2013 and approved by the ethics committee of Zahedan University of Medical Sciences (IR.ZAUMS.REC.1398.061 on 2019-04-29).

Consent to participate

Given that the teeth used in this study were extracted with the full consent of the patients to receive necessary medical services such as orthodontics, and were considered medical waste in this study, obtaining informed consent from the patients was not required.

Consent to publication

Not applicable.

Availability of data and materials

Data are available from the corresponding author upon reasonable request.

Funding

Not applicable.

Copyright

Publisher's note

References

1. Mamat R, Nik Abdul Ghani NR. The Complexity of the Root Canal Anatomy and Its Influence on Root Canal Debridement in the Apical Region: A Review. Cureus. 2023;15:e49024. [DOI] [PubMed] [PMC]
2. Siqueira JF Jr, Rôças IN, Paiva SSM, Guimarães-Pinto T, Magalhães KM, Lima KC. Bacteriologic investigation of the effects of sodium hypochlorite and chlorhexidine during the endodontic treatment of teeth with apical periodontitis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;104: 122–30. [DOI] [PubMed]
3. Saberi E, Zahedani SS, Ebrahimipour S. Apical Extrusion of Intracanal Bacteria with Single File and Multifile Rotary Instrumentation Systems. J Int Soc Prev Community Dent. 2017;7:292–6. [DOI] [PubMed] [PMC]
4. Sharma A, Sharma R, Sharma M, Jain S, Rai A, Gupta S. Endodontic Flare-Ups: An Update. Cureus. 2023; 15:e41438. [DOI] [PubMed] [PMC]
5. Udoye C, Aguwa E. Flare-up incidence and related factors in adults. J Dent Oral Hyg. 2010;2:19–22.
6. Sinhal TM, Shah RRP, Shah NC, Jais PS, Hadwani KD. Comparative evaluation of 2% chlorhexidine gel and triple antibiotic paste with calcium hydroxide paste on incidence of interappointment flare-up in diabetic patients: A randomized double-blinded clinical study. Endodontology. 2017;29:136–41. [DOI]
7. Nabavizadeh M, Shokouhi MM, Kheirandish M, Sahebi S, Sadatshojaee N, Abbaszadegan A. A Comparison of the Apical Extrusion of Debris during the Preparation of Root Canal with Medin, RaCe, and ProTaper Rotary Systems. J Dent (Shiraz). 2021;22:193–7. [DOI] [PubMed] [PMC]
8. Nouroloyouni A, Shahi S, Salem Milani A, Noorolouny S, Farhang R, Yousefi Azar A. In vitro apical extrusion of debris and instrumentation time following root canal instrumentation with Reciproc and Reciproc Blue instruments and a novel stainless steel rotary system (Gentlefile) versus manual instrumentation. J Dent Res Dent Clin Dent Prospects. 2023;17:136–41. [DOI] [PubMed] [PMC]
9. Grande NM, Castagnola R, Minciacchi I, Marigo L, Plotino G. A review of the latest developments in rotary NiTi technology and root canal preparation. Aust Dent J. 2023;68:S24–38. [DOI] [PubMed]

10. Dablanca-Blanco AB, Castelo-Baz P, Miguéns-Vila R, Álvarez-Novoa P, Martín-Biedma B. Endodontic Rotary Files, What Should an Endodontist Know? Medicina (Kaunas). 2022;58:719. [DOI] [PubMed] [PMC]
11. Yared G. Canal preparation using only one Ni-Ti rotary instrument: preliminary observations. Int Endod J. 2008;41:339–44. [DOI] [PubMed]
12. De-Deus G, Brandão MC, Barino B, Di Giorgi K, Fidel RAS, Luna AS. Assessment of apically extruded debris produced by the single-file ProTaper F2 technique under reciprocating movement. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010;110:390–4. [DOI] [PubMed]
13. Sedigh-Shams M, Ebrahimi R, Asheghi B, Eskandari F. Comparative Evaluation of Cyclic Fatigue Resistance of Two Single-file Rotary Instruments in Simulated Stainless Steel Curved Canals. J Res Dent Maxillofac Sci. 2022;7:48–54. Farsi. [DOI]
14. Bürklein S, Benten S, Schäfer E. Quantitative evaluation of apically extruded debris with different single-file systems: Reciproc, F360 and OneShape versus Mtwo. Int Endod J. 2014;47:405–9. [DOI] [PubMed]
15. Ghoneim WM, Shaheen NA. Apically extruded debris associated with different instrumentation systems and irrigation needles. Tanta Dent J. 2018;15:105–10. [DOI]
16. De-Deus G, Neves A, Silva EJ, Mendonça TA, Lourenço C, Calixto C, et al. Apically extruded dentin debris by reciprocating single-file and multi-file rotary system. Clin Oral Investig. 2015;19:357–61. [DOI] [PubMed]
17. Donyavi Z, Dehghan Banadkooki S, Ranjpour N, Karimi Mianji S. Comparison of Apically Extruded Debris Using Neoniti A1, ProTaper Gold, and WaveOne Gold Rotary Files in Mandibular Premolars: An In Vitro Study. Avicenna J Dent Res. 2024;16:232–7. [DOI]
18. Gürler K, Yilmaz S, Dumani A, Yoldas O. Comparison of cyclic fatigue resistance of three different single-file systems after clinical use. BMC Oral Health. 2024;24:1482. [DOI] [PubMed] [PMC]
19. Bane K, Faye B, Sarr M, Niang SO, Ndiaye D, Machtou P. Root canal shaping by single-file systems and rotary instruments: a laboratory study. Iran Endod J. 2015;10:135–9. [PubMed] [PMC]
20. Amaral RR, Love RM, Braga T, Souza Côrtes MI, Rachid CTCC, Rôças IN, et al. Impact of root canal preparation using two single-file systems on the intra-radicular microbiome of teeth with primary apical periodontitis. Clin Oral Investig. 2024;28:139. [DOI] [PubMed] [PMC]
21. Kucukyilmaz E, Savas S, Saygili G, Uysal B. Evaluation of Apically Extruded Debris and Irrigant Produced by Different Nickel-Titanium Instrument Systems in Primary Teeth. J Contemp Dent Pract. 2015;16:864–8. [DOI] [PubMed]
22. Uzun I, Güler B, Özyürek T, Tunc T. Apical extrusion of debris using reciprocating files and rotary instrumentation systems. Niger J Clin Pract. 2016;19:71–5. [DOI] [PubMed]
23. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol. 1971;32:271–5. [DOI] [PubMed]
24. 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. [DOI] [PubMed]
25. Azim AA, Azim KA, Abbott PV. Prevalence of inter-appointment endodontic flare-ups and host-related factors. Clin Oral Investig. 2017;21:889–94. [DOI] [PubMed]
26. Bassam S, El-Ahmar R, Salloum S, Ayoub S. Endodontic postoperative flare-up: An update. Saudi Dent J. 2021;33:386–94. [DOI] [PubMed] [PMC]
27. Capar ID, Arslan H, Akcay M, Ertas H. An *In Vitro* Comparison of Apically Extruded Debris and Instrumentation Times with ProTaper Universal, ProTaper Next, Twisted File Adaptive, and HyFlex Instruments. J Endod. 2014;40:1638–41. [DOI] [PubMed]
28. Ghivari SB, Kubasad GC, Chandak MG, Akarte N. Apical extrusion of debris and irrigant using hand and rotary systems: A comparative study. J Conserv Dent. 2011;14:187–90. [PubMed] [PMC]
29. Azar NG, Ebrahimi G. Apically-Extruded Debris Using The ProTaper System. Aust Endod J. 2005;31: 21–3. [DOI] [PubMed]

30. De-Deus GA, Nogueira Leal Silva EJ, Moreira EJ, de Almeida Neves A, Belladonna FG, Tameirão M. Assessment of Apically Extruded Debris Produced by the Self-Adjusting File System. J Endod. 2014;40: 526–9. [DOI] [PubMed]
31. Singbal K, Jain D, Raja K, Hoe TM. Comparative evaluation of apically extruded debris during root canal instrumentation using two Ni-Ti single file rotary systems: An *in vitro* study. J Conserv Dent. 2017;20:64–7. [PubMed] [PMC]
32. Gummadi A, Panchajanya S, Ashwathnarayana S, Santhosh L, Jaykumar T, Shetty A. 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. [PubMed] [PMC]
33. Ahmad MZ, Sadaf D, MacBain MM, Mohamed AN. Apical extrusion of debris with different rotary and reciprocating single-file endodontic instrumentation systems: a systematic review and meta-analysis protocol. BMJ Open. 2020;10:e038502. [DOI] [PubMed] [PMC]
34. Fau VJ, Bitter K, Fau BK, Kielbassa AM, Kielbassa A. Evaluation of rotary root canal instruments in vitro: A review. Endod Pract. 2007;1:189–203.
35. Siqueira JF Jr, Rôças IN, Favieri A, Machado AG, Gahyva SM, Oliveira JCM, et al. Incidence of Postoperative Pain After Intracanal Procedures Based on an Antimicrobial Strategy. J Endod. 2002;28: 457–60. [DOI] [PubMed]
36. Ehsani M, Farhang R, Harandi A, Tavanafar S, Raoof M, Galledar S. Comparison of Apical Extrusion of Debris by Using Single-File, Full-Sequence Rotary and Reciprocating Systems. J Dent (Tehran). 2016; 13:394–9. [PubMed] [PMC]
37. Nevares G, Xavier F, Gominho L, Cavalcanti F, Cassimiro M, Romeiro K, et al. Apical Extrusion of Debris Produced during Continuous Rotating and Reciprocating Motion. Sci World J. 2015;2015:267264. [DOI] [PubMed] [PMC]
38. Jaggi P, Mulay S, Tandale A, Jadhao R, Joshi P, Aras S, et al. Comparative Evaluation of Debris Extrusion, Remaining Dentin Thickness and Fracture Resistance of Endodontically Treated Teeth Using Rotary and Reciprocating Endodontic File Systems: An In Vitro Study. Cureus. 2023;15:e42290. [DOI] [PubMed] [PMC]
39. Diemer F, Calas P. Effect of Pitch Length on the Behavior of Rotary Triple Helix Root Canal Instruments. J Endod. 2004;30:716–8. [DOI] [PubMed]
40. Koch K, Brave D. Real world endo: design features of rotary files and how they affect clinical performance. Oral Health. 2002;92:39–49.
41. Labbaf H, Nazari Moghadam K, Shahab S, Mohammadi Bassir M, Fahimi MA. An In vitro Comparison of Apically Extruded Debris Using Reciproc, ProTaper Universal, Neolix and Hyflex in Curved Canals. Iran Endod J. 2017;12:307–11. [DOI] [PubMed] [PMC]
42. Elashiry MM, Saber SE, Elashry SH. Apical Extrusion of Debris after Canal Shaping with Three Single-file Systems. Niger J Clin Pract. 2020;23:79–83. [DOI] [PubMed]
43. Elnaghy AM. Cyclic fatigue resistance of ProTaper Next nickel-titanium rotary files. Int Endod J. 2014; 47:1034–9. [DOI] [PubMed]
44. Daugherty DW, Gound TG, Comer TL. Comparison of Fracture Rate, Deformation Rate, and Efficiency Between Rotary Endodontic Instruments Driven at 150 rpm and 350 rpm. J Endod. 2001;27:93–5. [DOI] [PubMed]
45. Peters OA, Morgental RD, Schulze KA, Paqué F, Kopper PMP, Vier-Pelisser FV. Determining cutting efficiency of nickel-titanium coronal flaring instruments used in lateral action. Int Endod J. 2014;47: 505–13. [DOI] [PubMed]
46. Tanalp J, Kaptan F, Sert S, Kayahan B, Bayirl G. Quantitative evaluation of the amount of apically extruded debris using 3 different rotary instrumentation systems. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2006;101:250–7. [DOI] [PubMed]

47. Topçuoğlu HS, Aktı 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;40:2066–9. [DOI] [PubMed]
48. Martin H, Cunningham WT. The effect of endosonic and hand manipulation on the amount of root canal material extruded. Oral Surg Oral Med Oral Pathol. 1982;53:611–3. [DOI] [PubMed]
49. Beeson TJ, Hartwell GR, Thornton JD, Gunsolley JC. Comparison of debris extruded apically in straight canals: Conventional filing versus profile .04 Taper series 29. J Endod. 1998;24:18–22. [DOI] [PubMed]