ISSN: 2581-5989
PubMed - National Library of Medicine - ID: 101738774

International Journal of Dental Science and Innovative Research (IJDSIR)

IJDSIR : Dental Publication Service

Available Online at:www.ijdsir.com

Volume – 8, Issue – 4, July – 2025, Page No. : 45 - 57

Comparison of Debris Extrusion during Root Canal Instrumentation Using a Rotary and a Reciprocating Motion Instrument: An in Vitro Study

[1]Erika Jasmine Argüello Gordillo, Faculty of Dentistry, Universidad Hemisferios, Quito-Ecuador

[2]Soo Nam Jang Jaramillo, Faculty of Dentistry, Universidad Hemisferios, Quito-Ecuador

Corresponding Author: Erika Jasmine Argüello Gordillo, Faculty of Dentistry, Universidad Hemisferios, Quito-Ecuador

Citation of this Article: Erika Jasmine Argüello Gordillo, Soo Nam Jang Jaramillo, "Comparison of Debris Extrusion during Root Canal Instrumentation Using a Rotary and a Reciprocating Motion Instrument: An in Vitro Study", IJDSIR- July – 2025, Volume – 8, Issue – 4, P. No. 45 – 57.

Type of Publication: Original Research Article

Conflicts of Interest: Nil

Abstract

To compare the amount of apically extruded debris during root canal instrumentation using the Endogal system with two types of motion (rotary and reciprocating) in comparison with R-Motion and One Curve.

Sixty single-rooted teeth were randomly divided into four groups ($n = 15$) according to the instrumentation system: Endogal (rotary motion), Endogal (reciprocating motion), R-Motion, and One Curve. Each instrument was used five times. Debris extrusion was assessed based on the experimental model reported by Myers and Montgomery (1991), and statistical analysis was performed using the Kruskal-Wallis test, Mann-Whitney U test, and Dunn's post hoc test with Bonferroni correction ($p < 0.05$).

The results showed that the Endogal system in rotary motion generated a greater amount of extruded debris compared to One Curve and the same system in reciprocating motion ($p < 0.01$). No statistically significant differences were found between the reciprocating systems evaluated (R-Motion and Endogal reciprocating), nor between One Curve and R-Motion. Additionally, no significant differences were observed in the amount of extruded debris across the five uses of each system.

This investigation concluded that the amount of apically extruded debris varies according to the design and motion of the instrumentation system. The Endogal system in rotary motion extruded significantly more debris compared to One Curve (rotary). Instrument´s reuse did not affect debris extrusion under the conditions of this study.

Keywords: Endodontics, apical extrusion, debris, rotary motion, reciprocating motion, File systems

Introduction

Debris extrusion produced during root canal instrumentation has been a topic of endodontic interest for several decades. Chapman et al. (1968) were the first to report extrusion during this process. Later, Van de Visse and Brilliant (1975) quantified this extrusion by evaluating instrumentation in irrigated and non-irrigated canals, concluding that irrigation facilitates the transport of debris toward the apex (1); (2); (3); (4); (5).

An essential part of root canal treatment is chemo-mechanical preparation, for which various instrumentation and irrigation systems are available on the market. However, even with strict control of the working length, apical extrusion of debris into the periapical tissues remains an inevitable occurrence (6); (7); (8); (9).

Minimizing this extrusion remains a clinical challenge that has yet to be fully controlled. Debris consists of dentin particles, irrigants, microorganisms, intracanal medications, or even fragments of endodontic instruments—elements that can negatively impact the prognosis of the treatment (6); (8); (10); (11).

In all cases—and especially those with apical periodontitis—it is essential to minimize extrusion as much as possible, since the extruded debris can cause periradicular inflammation, postoperative pain, affect the healing process, and may even lead to treatment failure (12); (10); (13); (6); (14); (15); (3); (16);(17)..

Several factors influence the amount of debris extruded beyond the apex. These include the anatomy and curvature of the canal, its permeability, the diameter of the apical preparation, the establishment of the working length, the type of motion of the systems, the number of files used, and their specific characteristics such as kinematics, taper, cross-sectional design, and cutting efficiency (13); (7); (18); (6); (19). In addition, the irrigation protocol also plays a key role, as both the type of needle and its placement distance from the foramen can significantly influence debris extrusion (20); (21).

Despite technological advances, no instrument has completely eliminated this phenomenon, as all systems cause some amount of debris extrusion into the periapical tissues (22); (8); (1); (14); (19) However, various studies have shown that factors such as the type of motion, irrigation technique, and the number of instruments used can influence the amount of extruded debris (6); (13); (4). Therefore, the collection and evaluation of apically extruded debris has become a key parameter for comparing the effectiveness of different techniques and instruments (7).

Although some recent studies have evaluated apical debris extrusion following the use of rotary and reciprocating instruments, no study has been found comparing this extrusion between the same Endogal system in both rotary and reciprocating motion. Therefore, the present study is the first in vitro investigation to compare the performance of Endogal (EG) instruments in rotary and reciprocating motion, which are also compared with R-Motion (RM) (reciprocating) and One Curve (OC) (rotary).

The hypothesis of this study is that there would be statistically significant differences among the three instrument systems used (EG, RM, OC) regarding their cutting efficiency over five uses and the amount of apically extruded debris.

Materials and Methods

Sample Selection

Eighty single-rooted teeth extracted for orthodontic or therapeutic reasons were collected from the “Clínica Odontológica Monar.” The teeth were cleaned of calculus and organic residues, immersed in 5.25% NaOCl for 10 minutes, and subsequently stored in 0.9%

saline solution until their use to prevent dehydration. Periapical radiographs were taken to ensure they met the inclusion criteria. Teeth with root caries, open apices, root resorptions, calcifications, fractures, or previous endodontic treatment were excluded (23). Only samples with a single canal classified as type 1-1 according to Vertucci's classification (1984) were included (24). Additionally, only canals with an initial apical diameter no greater than a size 10 K-file and a curvature between 10° and 20° according to Schneider's classification were included (25).

Sample size calculation

Sixty teeth meeting the inclusion criteria were selected and randomly distributed into four experimental groups of 15 samples each one, corresponding to the Endogal system in rotary motion, Endogal in reciprocating motion, R-Motion, and One Curve systems. The sample size was determined for convenience, based on previous studies with similar methodological designs (9); (26).

Standardization and patency

A conventional access cavity was prepared in the crown of each tooth using a high-speed round bur under copious water irrigation. The crowns were sectioned with a diamond disc at low speed under continuous irrigation to standardize the tooth length to 15 mm ± 1 mm. Canal patency was then confirmed using a #10 K-file (K-File, Kerr, Romulus, MI, USA) until the tip was visible at the apical foramen. The working length was established by subtracting 1 mm from the apical foramen

Preliminary preparation

Following the experimental model proposed by Myers and Montgomery (1991) (3). Each Eppendorf tube was weighed empty without the cap three times using a precision analytical balance provided by the "Universidad Internacional del Ecuador"; the average initial weight was calculated and recorded. A hole was then made in the cap of each Eppendorf tube to allow for tooth placement, and the teeth were secured with hot silicone. The teeth were inserted into their corresponding tubes, which were then positioned in a rubber dam stretched over the vial openings to prevent displacement and to blind the operator. A disposable 30 G hypodermic needle was also inserted into each cap to equalize internal and external air pressure. The instrumentation was performed by a single operator following the manufacturer's instructions for each system: Endogal in rotary motion, Endogal in reciprocating motion, R-Motion, and One Curve, using the E-Value endodontic motor (Eighteeth, China).

Figure 1: Root Canal Instrumentation

Groups

Group 1: Endogal (rotary) (ERO)

Group 2: Endogal (reciprocating) (ERE)

Group 3: R-Motion (RM)

Group 4: One Curve (OC)

Root canal treatment

During instrumentation, canals were irrigated with a total of 2 ml of 5.25% NaOCl, and patency was maintained using a #10 K-file. Irrigation was performed with a 30G side-vented NaviTip® needle (Ultradent Products Inc., South Jordan, Utah, USA) placed 3 mm short of the working length. After instrumentation, the canals were rinsed with saline solution, followed by a final irrigation protocol consisting of 1 ml of 17% EDTA for one minute, another saline solution rinse, 2 ml of 5.25% NaOCl, and a final rinse with saline solution (27).

Group 1: Endogal (rotary motion)

Endogal instruments were activated using the E-Value motor in continuous rotary motion at 300 rpm with a torque of 4 N·cm. The files were used in the sequence recommended by the manufacturer, starting with file X and ending with instrument D 25.06. The instruments were introduced using an in-and-out pecking motion until reaching the working length and were removed after three pecking motions. The same instruments were used on five different canals.

Group 2: Endogal (reciprocating motion)

Endogal instruments were activated with the E-Value motor in reciprocating motion (120°/30°) at a torque of 4 N·cm. The files were used in the sequence indicated by the manufacturer, from file X to instrument D 25.06. The instruments were applied using an in-and-out pecking motion until the working length was reached and removed after three pecking motions. The same instruments were used on five different canals.

Group 3: R-Motion

R-Motion instruments were activated with the E-Value motor in reciprocating motion at 150°/30°. A rotary glide path file was first introduced, followed by the 25.06 instrument. The instruments were operated with an in-and-out pecking motion until the working length was achieved and were removed after three pecking motions. The same instruments were used on five different canals.

Group 4: One Curve

One Curve instruments were activated with the E-Value motor in rotary motion at 300 rpm and a torque of 2.5 N·cm, following the manufacturer's protocol: first One Flare, then One G, and finally the One Curve instrument at 25.06. The instruments were used in an in-and-out pecking motion until the working length was reached and then removed after three pecking motions. The same instruments were used on five different canals.

Evaluation of apical extrusion

After instrumentation was completed, the teeth along with the caps of the Eppendorf tubes were removed from the vials. The roots were rinsed with 1 ml of distilled water to ensure that no debris remained on the external surface and that any residual particles fell into the corresponding Eppendorf tube. The tubes were then placed in an incubator for 10 days at 37.5°C. (8). At the end of this period, the tubes were removed from the incubator and weighed again three times to obtain an average final weight. The data collected was recorded in Excel spreadsheets and subsequently analyzed statistically.

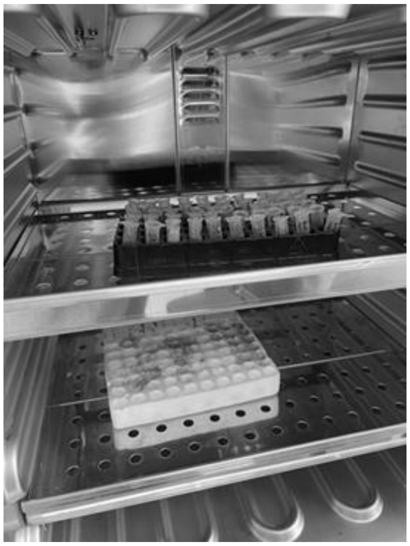


Figure 2: Eppendorf tubes post-instrumentation in the incubator.

Figure 3: Eppendorf Tubes Ready for Final Weighing

Statistical analysis of apical debris extrusion

To compare the amount of apically extruded debris among the R-Motion, One Curve, and Endogal systems in rotary and reciprocating motion, data were classified into four experimental groups according to system and kinematics. The Kruskal–Wallis test was used to compare the amount of debris extruded among the four groups. Subsequently, a Dunn's post hoc test with Bonferroni correction was applied to detect specific pairwise differences.

To compare R-Motion and Endogal in reciprocating motion, the Mann–Whitney U (Wilcoxon) test was used to assess differences in extruded debris between these two systems within the same kinematic type.

To compare One Curve and Endogal in rotary motion, groups 1 and 4 were analyzed. Due to non-normal data distribution, the Mann–Whitney U test was applied to determine whether significant differences existed in debris extrusion between the two rotary systems.

To evaluate the amount of debris extruded over five uses for each system, the corresponding samples were identified and labeled from 1 to 5 based on usage number. A Kruskal–Wallis test was performed separately within each system to determine whether the quantity of debris extruded varied across the five uses.

To compare the amount of apically extruded debris among the systems, the four experimental groups were considered.

Since the data did not meet the assumptions of normality (Shapiro–Wilk, $p < 0.05$ in 3 out of 4 groups), the non-parametric Kruskal–Wallis test was applied. The result was statistically significant ($\chi^2 = 18.05$, $p = 0.0004$), indicating at least one difference among the groups.

To identify which groups differed, a post hoc analysis was performed using Dunn's test with Bonferroni correction. The results showed that: Endogal in rotary motion (Group 1) extruded significantly more debris than:

- Endogal in reciprocating motion (Group 2): $p = 0.009$
- One Curve (Group 4): $p = 0.0006$

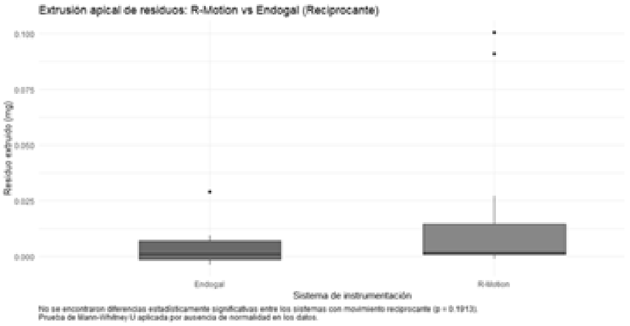
No significant differences were observed between:

- R-Motion and Endogal reciprocating ($p = 0.746$)
- Endogal rotary and R-Motion ($p = 0.611$)
- R-Motion and One Curve ($p = 0.138$)

These results suggest that the greatest apical debris extrusion was associated with the use of the Endogal system in rotary motion, whereas reciprocating systems showed similar behavior.

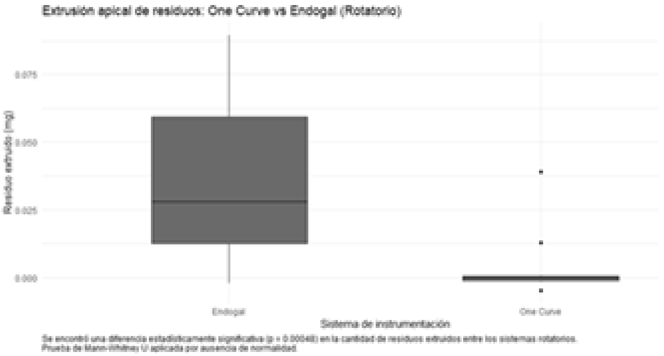
To specifically evaluate debris extrusion between the reciprocating systems—Endogal (Group 2) and R-Motion (Group 3)—the Mann–Whitney U test (Wilcoxon rank-sum test) was used. The result was not statistically significant (W = 80.5, $p = 0.1913$).

This indicates that, under the experimental conditions of this study, both reciprocating systems exhibited similar levels of apically extruded debris.



Graph 1: Apical Debris Extrusion: R-Motion vs Endogal (Reciprocating)

To determine the amount of debris extruded during instrumentation with One Curve and Endogal in rotary motion, the non-parametric Mann–Whitney U test was used due to the lack of normality in the data. The result showed a statistically significant difference (W = 193, $p = 0.00048$), indicating that the Endogal system in rotary motion extruded a greater amount of debris than the One Curve system. This finding highlights important differences between the rotary systems evaluated.



Graph 2: Apical Debris Extrusion: One Curve vs Endogal (Rotary)

To assess the variability in debris extrusion among different instruments within each root canal shaping system, data were grouped into blocks of five successive uses, corresponding to three separate instruments per system (Instrument 1: uses 1–5, Instrument 2: uses 6–10, Instrument 3: uses 11–15). Samples were previously labeled with alphanumeric identifiers (1A to 1O), allowing traceability of each observation by usage order and corresponding instrument.

The Kruskal–Wallis test was applied separately within each system to determine whether significant differences existed in the amount of extruded debris among the three instruments.

Results

A statistically significant difference was found only in the Endogal reciprocating group ($p = 0.0478$), suggesting potential variability in debris extrusion between instruments. No significant differences were observed in the other systems:

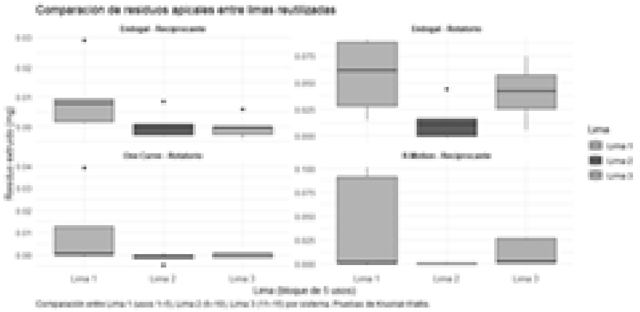
- Endogal – Rotary: $p = 0.0846$
- Endogal – Reciprocating: $p = 0.0478$
- R-Motion – Reciprocating: $p = 0.1312$
- One Curve – Rotary: $p = 0.3289$

These results indicate that, under the controlled conditions of this study, the amount of extruded debris remained relatively stable among instruments in most systems, except for the Endogal system in reciprocating motion.

Given the statistically significant difference found in the Endogal reciprocating group, a Dunn’s post hoc test with Bonferroni correction was conducted. While no pairwise comparison reached statistical significance after adjustment, there was a trend toward greater debris extrusion by the third instrument compared to the first (adjusted $p = 0.0709$).

Although R-Motion showed a relatively low median of extruded debris, no statistically significant differences were found when compared with the other systems ($p > 0.05$).

Based on the results, the hypothesis is accepted, as statistically significant differences were observed in the amount of apically extruded debris among some of the evaluated systems—particularly between One Curve and Endogal in rotary motion. Additionally, a significant difference was detected among instruments within the Endogal reciprocating system ($p = 0.0478$), although post hoc analysis did not confirm pairwise significance. These findings suggest that certain systems and usage conditions can influence the amount of debris extruded during instrumentation.



Graph 3: Comparison of Apical Debris Among Reused Instruments

Discussion

During root canal instrumentation, it is common for certain materials—such as dentin debris, remnants of pulp tissue, irrigants, and even microorganisms—to be extruded beyond the apical foramen, despite maintaining strict control over the working length. This apical extrusion into the periapical tissues can lead to inflammation, postoperative pain, and may negatively affect the healing process. Although all endodontic instrumentation systems cause some degree of extrusion, the amount varies depending on the technique used and the design of the instruments, including factors such as taper, cross-sectional shape, and the type of motion applied (28); (26); (29); (30).

In this in vitro study, the amount of apically extruded debris was compared using different instrumentation systems with rotary and reciprocating kinematics. The results showed that the Endogal system in rotary motion produced significantly more apical extrusion compared to One Curve and to Endogal used in reciprocating motion. On the other hand, no statistically significant differences were observed between the reciprocating systems evaluated (R-Motion and Endogal reciprocating), nor between One Curve and R-Motion.

The ERE and RM systems were operated using reciprocating motion, which, as explained by Topçuoğlu et al. (2016), combines counterclockwise and clockwise rotations. This motion reduces cyclic fatigue by minimizing the compressive and tensile stresses exerted on the instrument. In contrast, the OC and ERO systems operate in continuous rotary motion. Specifically, One Curve features a variable cross-sectional design, a .25 tip size, and a constant 6% taper. It is manufactured with C.Wire alloy, offering a balance of cutting efficiency, flexibility, and adaptability to root canal curvature (31) ; (11).

In the present study, OC was the system that exhibited the lowest amount of apically extruded debris. This outcome may be related to its usage protocol, which includes a preliminary coronal flaring instrument called One Flare. Instrumentation of the coronal third of the root canal is crucial, as it eliminates cervical interferences that may hinder access to the apical portion. Moreover, this step facilitates the entry of irrigants from the early stages and allows subsequent instruments to encounter less friction and contact with the canal walls, thereby reducing debris generation and apical pressure. Likewise, Topçuoğlu et al. (2016) notes that coronal flaring creates a space for debris accumulation, preventing its displacement toward critical areas. This may partly explain the favorable performance of OC regarding apical debris extrusion observed in this study.

In accordance with the results of the present study, there is evidence that the amount of apically extruded debris during instrumentation does not depend solely on the type of motion used, but rather on multiple combined factors. These include the number of instruments, their taper and cross-sectional design, and the presence or absence of a coronal pre-flaring or glide path preparation phase (31); (11).

In contrast, the ERO system, as explained by Azizi et al. (2021), despite including a coronal pre-flaring instrument, uses multiple instruments in its protocol, involving several cutting and corono-apical transport phases, which favor the accumulation and migration of debris toward the apex.

It is also relevant to mention that OC features a variable triangular tip cross-section that transitions into an italic S-shape closer to the shaft. Predin Djuric (2021) states that this design allows for greater debris removal in the coronal direction due to increased intracanal space and deeper flutes, facilitating coronal debris transport. In contrast, Endogal has a continuous parallelogram-shaped cross-section.

Azizi et al. (2021) indicate that the number of instruments used influences the amount of extruded debris. This contrasts with the findings of Bürklein et al. (2016), who demonstrated that the use of multiple instruments, compared to single-file systems, does not appear to be directly related to the amount of debris extruded. In their study, the F360 and One Shape systems extruded significantly less debris than Reciproc, which showed no statistically significant differences compared to the multi-file Mtwo system. Similarly, the study by Caviedes et al. (2016) concluded that the number of instruments used does not influence the inflammatory response. Instead, it is the type of motion and the instrument design that play a more significant role (4).

In the study conducted by Caviedes et al. (2016), which compared R-Motion with ProTaper Next and WaveOne Gold, R-Motion showed the best results in terms of debris extrusion. This performance may be attributed to its slim core combined with a spherical tip. Additionally, its triangular cross-sectional design may explain the lower amount of extruded debris, as this shape enhances instrument flexibility and facilitates debris removal. In fact, the authors suggest that instrument design may have a more decisive influence on debris production than the number of instruments used.

However, in the present study, when R-Motion was compared with instruments of similar diameter and taper, it did not show the best results. This could be due to differences in cross-sectional design among systems and the presence of a pre-flaring instrument in the protocols of some systems.

The lower amount of apically extruded debris associated with reciprocating systems is not a consistent finding across different studies (26). Bürklein (2016), in his study, concluded that rotary motion was associated with a lower amount of debris extrusion (9). The reciprocating systems RM and ERE showed similar behavior overall. However, the fact that ERE extruded less debris compared to RM could be attributed to the inclusion of a pre-flaring instrument, known as "X", in its protocol—a step not presented in the R-Motion system. This aligns with previous studies reporting that reciprocating motion, when combined with adequate coronal pre-flaring, can promote debris transport toward the coronal portion of the canal (28). These observations reinforce the importance of considering not only the type of motion but also the instrument design and the complete clinical sequence when selecting an instrumentation system that minimizes apical extrusion.

Regarding Endogal, there are conflicting reports on the effects of reciprocating versus rotary motion. One study that evaluated the same instrument (Reciproc) in both rotary and reciprocating motion found that reciprocating motion resulted in less apical debris extrusion. This may be since greater cutting efficiency, when combined with reciprocating motion, could enhance debris transport toward the apex (29)

According to the literature, irrigating closer to the foramen (at 1 mm) tends to improve canal cleanliness by facilitating the removal of debris in that area. However, it also increases the risk of greater extrusion of debris and irrigants beyond the apical foramen, which can lead to complications such as inflammation, postoperative pain, or even accidents involving NaOCl (12).

In the present study, the irrigation needle was positioned 3 mm short of the working length. This decision was based on findings reported in various studies, which suggest that this distance offers a balance between effective canal cleaning and minimizing the risk of apical extrusion of irrigants and debris (21); (12); (8) These studies suggest that maintaining the irrigation needle tip approximately 2–3 mm from the apex reduces the extrusion of irrigants and debris into the periapical tissues. The use of side-vented needles and passive insertion also helps control irrigant pressure and prevent complications.

In this study, instrumentation was performed 1 mm short of the apical foramen, following the recommendation of the study by Myers and Montgomery (1991) (3), it is indicated that this distance is appropriate to allow effective canal cleaning without compromising the periapical tissues. Other studies propose that instrumenting up to the foramen improves disinfection in cases with periapical lesions; however, those same studies report no significant differences in debris extrusion between both techniques when standardized irrigation protocols are used (20); (32).

In previous in vitro studies on debris extrusion, some researchers have used distilled water instead of NaOCl to avoid sodium crystallization, while others have chosen to use NaOCl (6); (33). In this study, NaOCl was selected as the irrigating solution during instrumentation to simulate clinical conditions, following the approach of Nevares et al. (2015). This allowed for the evaluation of the biological impact of the irrigant, considering NaOCl's ability to dissolve organic debris and dentin, which may increase debris extrusion compared to distilled water (16).

It is important to note that the study was conducted using extracted teeth with apices exposed to air, without simulating the presence of periapical tissues. This lack of back pressure means that the results should be interpreted with caution when applied clinically. Additionally, the effect of gravity may have facilitated the outflow of irrigant and consequently of debris from the canal. These methodological limitations have already been highlighted by authors such as Myers and Montgomery (1991), as well as in more recent studies conducted under similar experimental conditions (26); (9); (3).

Previous studies have demonstrated that both the type and concentration of the irrigant can significantly influence the amount of apically extruded debris. Gokturk et al. (2020) reported that 5.25% NaOCl generated a greater amount of debris compared to lower concentrations (2.5%) and to 2% chlorhexidine. Similarly, Mirsattari et al. (2024) noted that the use of EDTA resulted in increased debris extrusion due to its chelating action, thus establishing a direct relationship between the irrigant used and the amount of debris expelled (17); (34).

In addition, irrigants with lower surface tension, such as liquid EDTA and peracetic acid, allow for greater wettability and penetration into the dentinal tubules, thereby enhancing the cleaning of the root canal system (17). For this reason, EDTA was included in the final irrigation protocol in the present study.

Although it has been reported that EDTA can have detrimental effects on dentin, such as altering its chemical composition and reducing its microhardness (35) it has also been shown to enhance the antimicrobial efficacy of root canal sealers. One study revealed that the removal of the smear layer with EDTA improves the penetration of resin-based sealers such as AH Plus. Therefore, the importance of using balanced irrigation protocols is emphasized, as they are key to optimizing disinfection and the effectiveness of endodontic obturation (36); (37).

In contrast, Ramírez-Bommer et al. (2018) observed that the combined use of NaOCl and EDTA enhances the penetration of both agents, as NaOCl removes organic content while EDTA acts on the mineral substrate. This combination optimizes the cleaning of the root canal system by eliminating barriers that could interfere with the action of the irrigant (38).

Regarding instrument reuse, the study conducted by Restrepo et al. (2018) found that although certain mechanical properties—such as flexibility and resistance to cyclic fatigue—showed some improvement after multiple cycles of use and sterilization, changes were also observed in the surface topography and chemical composition of the material. These alterations raise concerns about the structural integrity of the instruments, leading the authors to suggest that the reuse and sterilization process is not advisable if the goal is to maintain instrument quality and safety (39). Additionally, a study evaluating the effectiveness of various disinfection methods for endodontic instruments found that no technique eliminated biological residues. This highlights that the reuse of instruments poses a potential risk of cross-contamination and, therefore, is not recommended in clinical practice (27).

Conclusions

Under the conditions of this in vitro study, the Endogal system in rotary motion extruded a greater amount of apical debris compared to One Curve and to the same system operating in reciprocating motion. No statistically significant differences were found between the reciprocating systems evaluated, nor between One Curve and R-Motion, indicating similar behavior regarding apical extrusion. Additionally, the reuse of instruments for up to five consecutive uses did not show significant differences in the amount of extruded debris.

References

1. Abdelnaby, P., Ibrahim, M., & ElBackly, R. (2023). In vitro evaluation of filling material removal and apical debris extrusion after retreatment using Reciproc blue, Hyflex EDM and ProTaper retreatment files. BMC Oral Health, 23(1). https:// doi.org/10.1186/S12903-023-03579-7
2. Al-Omari, M. A. O., & Dummer, P. M. H. (1995). Canal blockage and debris extrusion with eight preparation techniques. Journal of Endodontics, 21(3), 154–158. https://doi.org/10.1016/S0099-2399 (06)80443-7
3. Al-Saffar, F. B., & Al-Gharrawi, H. A. (2023). A Comparative Evaluation of the Apically Extruded Debris from Root Canals Prepared by R-Motion NiTi File System. International Journal of Dentistry, 2023, 5731248. https:// doi.org/ 10.1155/ 2023/ 5731248
4. Alves, F. R. F., Paiva, P. L., Marceliano-Alves, M. F., Cabreira, L. J., Lima, K. C., Siqueira, J. F., Rôças, I. N., & Provenzano, J. C. (2018). Bacteria and Hard Tissue Debris Extrusion and Intracanal Bacterial Reduction Promoted by XP-endo Shaper and Reciproc Instruments. Journal of Endodontics, 44(7), 1173–1178. https://doi.org/ 10.1016/ J.JOEN. 2018.04.007
5. Amaral, A. P., Limongi, P. B. O. C., Fontana, C. E., Martin, A. S. De, Bueno, C. E. D. S., & Pinheiro, S. L. (2019). Debris Apically Extruded by Two Reciprocating Systems: A Comparative Quantitative Study. European Journal of Dentistry, 13(4), 625–628. https://doi.org/10.1055/S-0039-3400550
6. Arias-Moliz, M. T., & Camilleri, J. (2016). The effect of the final irrigant on the antimicrobial activity of root canal sealers. Journal of Dentistry,

52, 30–36. https:// doi.org/ 10.1016/ J.JDENT. 2016.06.008

7. Arslan, H., Doğanay, E., Alsancak, M., Çapar, I. D., Karataş, E., & Gündüz, H. A. (2016). Comparison of apically extruded debris after root canal instrumentation using Reciproc® instruments with various kinematics. International Endodontic Journal, 49(3), 307–310. https://doi.org/ 10.1111/ IEJ.12449
8. Azizi, A., Prati, C., Schiavon, R., Fitzgibbon, R., Pirani, C., Iacono, F., Pelliccioni, G. A., Spinelli, A., Zamparini, F., Puddu, P., Bolelli, G., & Generali, L. (2021). In-depth metallurgical and microstructural analysis of oneshape and heat treated onecurve instruments. European Endodontic Journal, 6(1), 90–97. https://doi.org/10.14744/EEJ.2021.63634,
9. Boutsioukis, C., Verhaagen, B., Versluis, M., Kastrinakis, E., Wesselink, P. R., & van der Sluis, L. W. M. (2010). Evaluation of Irrigant Flow in the Root Canal Using Different Needle Types by an Unsteady Computational Fluid Dynamics Model. Journal of Endodontics, 36(5), 875–879. https:// doi.org/10.1016/j.joen.2009.12.026
10. Bürklein, S., Benten, S., & Schäfer, E. (2014). Quantitative evaluation of apically extruded debris with different single-file systems: Reciproc, F360 and OneShape versus Mtwo. International Endodontic Journal, 47(5), 405–409. https:// doi.org/ 10.1111/IEJ.12161,
11. Caviedes-Bucheli, J., Castellanos, F., Vasquez, N., Ulate, E., & Munoz, H. R. (2016). 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. International Endodontic Journal, 49(3), 255–270. https://doi.org/10.1111/IEJ.12452
12. De-Deus, G., Brandão, M. C., Barino, B., Giorgi, K. Di, Fidel, R. A. S., & Luna, A. S. (2010). Assessment of apically extruded debris produced by the single-file ProTaper F2 technique under reciprocating movement. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics, 110(3), 390–394. https://doi.org/ 10. 1016/J.TRIPLEO.2010.04.020
13. Doğanay Yıldız, E., & Arslan, H. (2019). The effect of blue thermal treatment on endodontic instruments and apical debris extrusion during retreatment procedures. International Endodontic Journal, 52(11), 1629–1634. https:// doi.org/ 10.1111/ IEJ. 13161
14. Gokturk, H., Ozkocak, I., Aydin, U., & Serefli, E. D. (2020). Effect of different chelating agents and their surface tension on the amount of apically extruded debris. Journal of Dental Sciences, 16(1), 195. https://doi.org/10.1016/J.JDS.2020.06.015
15. Gunes, B., & Yesildal Yeter, K. (2018). Effects of Different Glide Path Files on Apical Debris Extrusion in Curved Root Canals. Journal of Endodontics, 44(7), 1191–1194. https://doi.org/ 10. 1016/j.joen.2018.04.012
16. Kaşıkçı Bilgi, Köseler, Güneri, P., Hülsmann, M., & Çalışkan, M. K. (2017). Efficiency and apical extrusion of debris: a comparative ex vivo study of four retreatment techniques in severely curved root canals. International Endodontic Journal, 50(9), 910–918. https:// doi.org/ 10.1111/IEJ.12708; C TYPE:STRING:JOURNAL
17. Mirsattari, S., Jahromi, M. Z., & Khabiri, M. (2024). Evaluation of apically extruded debris from root canal filling removal of the mesiobuccal canal of

maxillary molars using XP shaper and protaper with two different irrigation. Dental Research Journal, 21(1), 65. https://doi.org/10.4103/DRJ.DRJ_703_22

18. Myers, G. L., & Montgomery, S. (1991). A comparison of weights of debris extruded apically by conventional filing and canal master techniques. Journal of Endodontics, 17(6), 275–279. https://doi.org/10.1016/S0099-2399(06)81866-2
19. Nevares, G., Xavier, F., Gominho, L., Cavalcanti, F., Cassimiro, M., Romeiro, K., Alvares, P., Queiroz, G., Sobral, A. P., Gerbi, M., Silveira, M., & Albuquerque, D. (2015). Apical Extrusion of Debris Produced during Continuous Rotating and Reciprocating Motion. The Scientific World Journal, 2015, 267264. https://doi.org/10.1155/2015/267264
20. Pedullà, E., Iacono, F., Pitrolo, M., Barbagallo, G., La Rosa, G. R. M., & Pirani, C. (2023). Assessing the impact of obturation techniques, kinematics and irrigation protocols on apical debris extrusion and time required in endodontic retreatment. Australian Endodontic Journal, 49(3), 623–630. https:// doi.org/ 10.1111/AEJ.12795;CTYPE:STRING:JOURNAL
21. Popovic, J., Gasic, J., Zivkovic, S., Petrovic, A., & Radicevic, G. (2010). Evaluation of biological debris on endodontic instruments after cleaning and sterilization procedures. International Endodontic Journal, 43(4), 336–341. https://doi.org/ 10.1111/ J.1365-2591.2010.01686.X,
22. Predin Djuric, N., Van Der Vyver, P., Vorster, M., & Vally, Z. I. (2021). Comparison of apical debris extrusion using clockwise and counter-clockwise single-file reciprocation of rotary and reciprocating systems. Australian Endodontic Journal, 47(3), 394–400. https://doi.org/10.1111/AEJ.12490,
23. Ramírez-Bommer, C., Gulabivala, K., Ng, Y. L., & Young, A. (2018). Estimated depth of apatite and collagen degradation in human dentine by sequential exposure to sodium hypochlorite and EDTA: a quantitative FTIR study. International Endodontic Journal, 51(4), 469–478. https://doi.org/ 10.1111/ IEJ.12864,
24. Restrepo-Restrepo, F. A., Holguín-Vásquez, V. A., Cañas-Jiménez, S. J., Villa-Machado, P. A., Ochoa-Soto, S., Ossa-Orozco, C. P., & Tobón-Arroyave, S. I. (2021). Microstructural, microchemical, and mechanical changes associated with the clinical reuse of two nickel–titanium endodontic instruments. Dental Research Journal, 18(1), 48. https://doi.org/10.4103/1735-3327.318943
25. Retana-Lobo, C., Ramírez-Mora, T., Murillo-Gómez, F., Maria Guerreiro-Tanomaru, J., Tanomaru-Filho, M., & Reyes-Carmona, J. (2022). Final irrigation protocols affect radicular dentin DMP1-CT expression, microhardness, and biochemical composition. Clinical Oral Investigations, 26(8), 5491–5501. https://doi.org/ 10.1007/S00784-022-04516-8,
26. Schneider, S. W. (1971). A comparison of canal preparations in straight and curved root canals. Oral Surgery, Oral Medicine, Oral Pathology, 32(2), 271–275. https://doi.org/10.1016/0030-4220(71)90230-1,
27. Seltzer, S., & Naidorf, I. J. (1985). Flare-ups in endodontics: I. Etiological factors. Journal of Endodontics, 11(11), 472–478. https://doi.org/ 10.1016/ S0099-2399(85)80220-X
28. Silva, E. J. N. L., Carapiá, M. F., Lopes, R. M., Belladonna, F. G., Senna, P. M., Souza, E. M., & De-Deus, G. (2016a). Comparison of apically extruded debris after large apical preparations by full-sequence rotary and single-file reciprocating systems. International Endodontic Journal, 49(7), 700–705. https://doi.org/10.1111/IEJ.12503,

29. Silva, E. J. N. L., Carapiá, M. F., Lopes, R. M., Belladonna, F. G., Senna, P. M., Souza, E. M., & De-Deus, G. (2016b). Comparison of apically extruded debris after large apical preparations by full-sequence rotary and single-file reciprocating systems. International Endodontic Journal, 49(7), 700–705. https://doi.org/10.1111/IEJ.12503,
30. Silva, E. J. N. L., Sá, L., Belladonna, F. G., Neves, A. A., Accorsi-Mendonça, T., Vieira, V. T. L., De-Deus, G., & Moreira, E. J. (2014). Reciprocating versus rotary systems for root filling removal: Assessment of the apically extruded material. Journal of Endodontics, 40(12), 2077–2080. https://doi.org/10.1016/j.joen.2014.09.009
31. Silva, E. J. N. L., Teixeira, J. M., Kudsi, N., Sassone, L. M., Krebs, R. L., & Coutinho-Filho, T. S. (2016). Influence of apical preparation size and working length on debris extrusion. Brazilian Dental Journal, 27(1), 28–31. https://doi.org/10.1590/0103-6440201600337,
32. Siqueira, J. F. (2003). Microbial causes of endodontic flare-ups. International Endodontic Journal, 36(7), 453–463. https://doi.org/ 10.1046/ J.1365-2591.2003.00671.X
33. Tanalp, J. (2022). A critical analysis of research methods and experimental models to study apical extrusion of debris and irrigants. International Endodontic Journal, 55(S1), 153–177. https:// doi. org/ 10.1111/IEJ.13686
34. Tanalp, J., & Güngör, T. (2014). Apical extrusion of debris: A literature review of an inherent occurrence during root canal treatment. International Endodontic Journal, 47(3), 211–221. https://doi.org/ 10.1111/IEJ.12137
35. Tanalp, J., Kaptan, F., Sert, S., Kayahan, B., & Bayirl, G. (2006). Quantitative evaluation of the amount of apically extruded debris using 3 different rotary instrumentation systems. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics, 101(2), 250–257. https://doi.org/ 10. 1016/J.TRIPLEO.2005.03.002
36. Topçuoğlu, H. S., Üstün, Y., Akpek, F., Aktı, A., & Topçuoğlu, G. (2016). Effect of coronal flaring on apical extrusion of debris during root canal instrumentation using single-file systems. International Endodontic Journal, 49(9), 884–889. https://doi.org/10.1111/IEJ.12520,
37. Vertucci, F. J. (1984). Root canal anatomy of the human permanent teeth. Oral Surgery, Oral Medicine, Oral Pathology, 58(5), 589–599. https:// doi.org/10.1016/0030-4220(84)90085-9
38. Yeter, K. Y., Evcil, M. S., Ayranci, L. B., & Ersoy, I. (2013). Weight of apically extruded debris following use of two canal instrumentation techniques and two designs of irrigation needles. International Endodontic Journal, 46(9), 795–799. https://doi.org/10.1111/IEJ.12060,
39. Zancan, R. F., Di Maio, A., Tomson, P. L., Duarte, M. A. H., & Camilleri, J. (2021). The presence of smear layer affects the antimicrobial action of root canal sealers. International Endodontic Journal, 54(8), 1369–1382. https://doi.org/ 10.1111/ IEJ. 13522,