Vol: 8 Issue: 2

EDJ

Impact of Various File Systems on Apical Debris Extrusion in Single Canal Teeth: An in Vitro Study

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ABSTRACT

Background and Objectives: This study aims to analyze and correlate the quantity of debris extruded from apical foramen amid root canal instrumentation applying Mtwo, ProTaper Next, and Race Evo file systems.

Materials and Method: A collection of sixty single-rooted, single-canal premolars were selected. The roots were divided randomly into three different groups (n = 20 each) based on the type of instrumentation system used: Group 1 – "ProTaper Next ," Group 2 – "RACE EVO ," and Group 3 – "Mtwo ." The debris extruded during instrumentation was collected, dried in pre-weighed vials, and measured using an electronic balance.

Results: There was a highly significant difference in apically extruded debris among the three file systems. Mtwo had the lowest debris extrusion (0.00054 ± 0.00018), while Protaper Next had the highest mean debris extrusion (0.00101 ± 0.00020), followed by RACE EVO (0.00077 ± 0.00024).

Conclusion: Mtwo with continuous rotation exhibited the most advantageous performance of the evaluated systems due to its S-shaped cross-section and effective debris removal capabilities

Keywords: Debris extrusion, ProTaper Next, RACE EVO, Mtwo

Article Information

Submission Date: 26/5/2025
Revision date: 29/6/2025
Acceptance date: 18/8/2025
Publishing date: Dec 2025

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DOI: doi.org/10.15218/edj.2025.22

Vol: 8 Issue: 2 Date: Dec 2025

INTRODUCTION

A successful root canal procedure depends on efficiently eliminating pulp tissue, bacteria, and debris with the least amount of damage to the periapical tissues. However, poor healing, inflammation, and postoperative discomfort might result from the inescapable debris extruded apically throughout root canal treatments,[1] The overall quantity of debris is influenced by factors like the technique of instrumentation, file design, and the rotary system kinematics.[2]

The efficiency of canal preparation during root canal preparation has been remarkably improved using Nickel-titanium (NiTi) rotary instruments by increasing flexibility, which minimizes procedural errors and preserves the canal anatomy3. Owing to their specific metallurgy and distinct design, file systems such as ProTaper Next, Mtwo, and RACE EVO are among the most common tools used by dentists for root canal treatments. Effortless dentin cutting and debris removal by the Mtwo system, attributed to its S-shaped cross-section, positive rake angle, and modified pitch design.[4] Rectangular cross-section, which is a recognizable feature of ProTaper Next file system that provides a reduction in torsional stress and enhances efficiency, and cutting flexibility, affecting the amount of extruded debris.[5] RACE EVO, a heat-treated NiTi, which is a recent version of the RaCe system, with its triangular cross-section, non-cutting tip, and alternating cutting flutes, maximizes flexibility and debris evacuation while minimizing debris extrusion.[6]

Debris extrusion is a major concern that cannot be disregarded, as it affects patients' comfort postoperatively, despite the continuous advances in file design and instrumentation. The most common method to quantify extruded debris is the vial-weighting approach, which includes collecting and weighing the extruded debris within a vial or an Eppendorf tube,[7] ensuring a meticulous quantification. A rubber stopper with a tooth is attached to the vial, which has been measured on a high-precision electronic scale, to isolate the apical foramen. During root canal instrumentation, debris and irrigant can leak into the vial. Afterward, to evaporate moisture, the vial was preserved in an incubator. The quantity of extruded debris is determined by measuring the difference between the initial and final weights through a subsequent weighing. This standardized method is often used for assessing various instrumentation systems since it provides accurate and dependable measurements.[1]

This study compares and assesses the quantity of apically extruded debris amid root canal preparation using the Mtwo, ProTaper Next, and RACE EVO file systems. The null hypothesis is that there is no statistically significant difference in the quantity of apically extruded debris among these three file systems. These results can help determine the most efficient file system that minimizes apical debris extrusion, enabling an understanding of the clinical value of different systems and their possible effect on postoperative outcomes.

METHODS

Sample Selection and Preparation

Sixty freshly extracted human mandibular premolars, with well-formed apices and a single straight canal, were selected for this study. The teeth had been collected from people aged 15 to 35 who had undergone extractions for periodontal or orthodontic reasons. After extraction, with the use of a periodontal scaler, all calculus and soft tissue remnants were removed from root surfaces. Radiographic testing was conducted in mesiodistal and buccolingual views to ensure that the canal is single and unobstructed. Teeth with multiple canals, calcifications, fractures, or earlier endodontic treatments were removed from the study.

To standardize root length and eliminate variation related to coronal anatomy, at the level of cementoenamel junction (CEJ), all teeth were decoronated by a slow-speed straight handpiece equipped with a diamond disc under continuous water irrigation. This method resulted in a uniform root length of 12 mm (Figure 1). The pulpal tissue was extirpated. A size #10 stainless steel K-file was inserted into the canal until its tip was visible at the apical foramen, and the working length (WL) was determined by subtracting 1 mm from this measurement. To confirm apical patency, a size #15 K-file was inserted into the WL. Teeth were excluded from the study if the file extruded beyond the foramen.

Figure 1. Root length determination

Grouping and Experimental Design

The selected roots were randomly ordered into three experimental groups (n = 20) based on the rotary instrumentation system used(Figure 2):

- **Group 1:** ProTaper Next (PTN)
- **Group 2:** Mtwo (MTW)
- **Group 3:** RACE EVO (RE)

New instruments were used for each specimen to prevent variations caused by file wear or deformation.

Figure 2. Rotary file systems : A- RACE EVO B-Mtwo C-ProTaper Next

Experimental Model for Debris Collection

The method described by Myers and Montgomery (1991) was utilized to collect and quantify apically extruded debris. Each root was embedded into a rubber stopper with a pre-drilled hole, ensuring that the root extended 1–2 mm above the stopper while maintaining a stable and airtight fit. Adjacent to the tooth, a 27-G needle was inserted to function as a ventilation conduit, allowing pressure equalization between the internal and external environments of the vial. The entire setup, including the tooth, rubber stopper, and vial, was isolated with a rubber dam to avoid operator bias by obstructing visibility of the apical extrusion process(Figure 3).

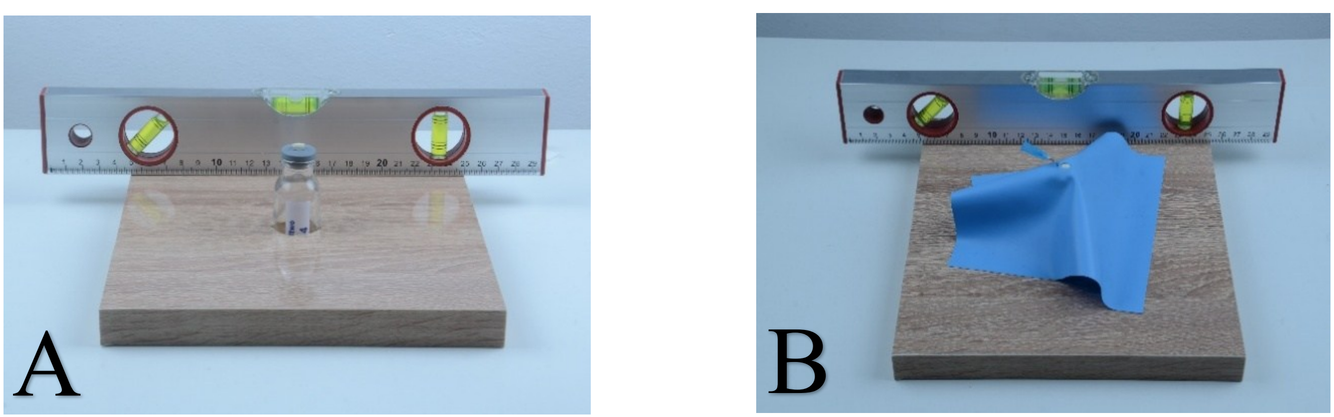

Figure 3. Debris collecting apparatus (A- without rubber dam, B- with rubber dam and 27-G needle ventilation)

DOI: doi.org/10.15218/edj.2025.22

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Pre-weighing of the Glass Vials

Each glass vial was pre-weighed using a high-precision Digital analytical balance (RADWAG Poland) with a preciseness of 10^{-4}g (Figure 4). To ensure consistency and accuracy, five consecutive weight values were recorded for each vial, and the average value was calculated and used as the baseline weight.

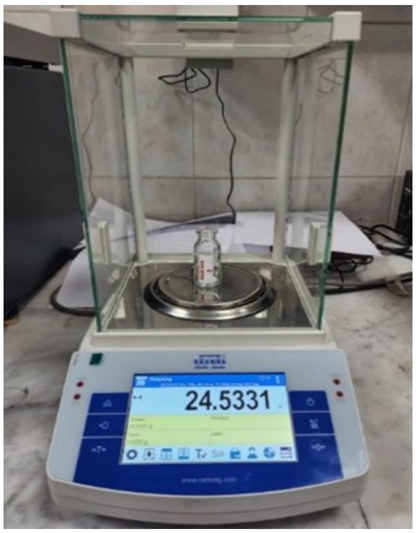

Figure 4. Analytical balance (RADWAG Poland)

Root Canal Instrumentation Protocols

All file systems in this study used with continuous rotation.

ProTaper Next (PTN) Group

Root canal instrumentation in this group was conducted using the ProTaper Next (Dentsply Tulsa Dental, USA) rotary file system with an X-Smart endodontic motor (Dentsply Tulsa Dental) set at 300 rpm and 3 N-cm torque (According to manufacturer instructions). The first file X1 file (17/.04) was inserted into the canal until resistance was encountered, at which point it was withdrawn, cleaned, and checked before reuse. The irrigation of the canal was performed via distilled water (2mL) utilizing a side-vented 27-G needle, followed by patency confirmation and recapitulation with a K-file size #10. The instrumentation sequence continued with the X2 file (25/.06) following the same protocol until the WL was reached. Irrigation was standardized using a VATEA irrigation device, which delivered distilled water at a controlled flow rate of 1 mL/min with the use of an irrigation needle (27-G side-vented) that was placed 1mm short of the WL, moved in a gentle up-and-down motion to enhance debris removal.

RACE EVO (RE) Group

Instrumentation in the current group was done using the RACE EVO (FKG Dentaire, Switzerland) rotary system, which works at 600 rpm and 1.5 N-cm torque. The sequence began with the 15/.04file, which was introduced into the canal using a gentle pecking motion until it reached the middle third, followed by irrigation with 2mL of distilled water. Next, the 25/.04 file was used to advance further apically while confirming patency with a #10 K-file. Finally, the 25/.06 file was introduced to the WL following the same technique. The irrigation protocol was standardized as in the previous groups via the VATEA irrigation device.

Mtwo (MTW) Group

Root canal preparation for this group was carried out with the Mtwo (VDW, Germany) rotary system in continuous rotation at 300 rpm and 1.5 N-cm torque. The 10/.04 file was utilized using a brushing motion until it encountered resistance, following which it was retrieved, cleaned, and inspected. The canal has been irrigated with 2 mL of distilled water, and patency confirmed with a K-file size #10. The technique was subsequently repeated with the 15/.05, 20/.06, and 25/.06 until the WL was reached. The irrigation protocol was the same across all groups via the VATEA irrigation device.

Post-instrumentation Debris Collection and Weighing

Once the instrumentation was completed, the rubber stopper, tooth, and ventilation needle were carefully disengaged from each vial. adherent external root surface debris was cleared away with the use of 2mL of distilled water, ensuring that all extruded debris was collected within the vial. Then an incubator set on 60°C was used to house the vials for five days for the complete evaporation of distilled water, assuring that only dry debris remains. The final weight calculation was conducted by a second examiner who was blinded to the experimental groups. With the use of the very analytical balance, five weight measurements were taken successively.

By subtracting the initial pre-weighed vial weight from the post-instrumentation weight, the net weight of the extruded debris was obtained.

Statistical Analysis

Means ± standard deviations were calculated to describe the samples' intended characteristics. With a significance level of p<0.05, the wire types were compared before and after using the paired t-test technique and the independent samples t-test between the wire types at both time periods. The normality assumption was put to the test using the Shapiro-Wilks.

Assessment of Normality and Homogeneity of Variances

The assumptions of normality and homogeneity of variances were evaluated prior to the file systems being compared as shown in Table 1. A normal distribution of the data was shown by the Shapiro-Wilk test, which revealed p-values larger than 0.05 for all groups across the Mean Differences readings. The homogeneity of variances was further confirmed by the non-significant p-values obtained from the Evene's test (Mean Differences: 0.958). These findings support the goal of the study by validating the use of parametric testing to correlate the quantity of apically extruded debris among the ProTaper Next, RACE EVO, and Mtwo systems.

Table 1. Shapiro-Wilk and levene's test results for normality and homogeneity across groups

Readings	Groups	Shapiro-Wilk Test	Levene Test
		Statistic (P-value)	Statistic (P-value)
Mean_Differences	ProTaperNext	0.963 (0.605)	0.043 (0.958)
	RACE EVO	0.850 (0.055)	
	MTwo	0.949 (0.351)	

Comparison of Mean Values and Analysis of Variance (ANOVA) among Instrumentation Groups

For every reading, the ANOVA results and descriptive statistics are displayed from Table 2. There was a highly significant difference between the file systems was found by analyzing Mean Differences, which represent the actual amount of apically extruded debris (F = 24.187, p < 0.001). Mtwo had the lowest debris extrusion (0.00054 ± 0.00018), while ProTaper Next had the highest mean debris extrusion (0.00101 ± 0.00020), followed by RACE EVO (0.00077 ± 0.00024). The study's goal is directly addressed by these results, which show a pronounced difference in the file systems' debris extrusion performance.

Table 2. Descriptive statistics (Mean ± SD (min, max)) and ANOVA results for mean differences

	ProTaperNext Mean ± SD (min, max)	RACE EVO Mean ± SD (min, max)	MTwo Mean ± SD (min, max)	F Value (P-value)
Differences (n=20)	0.00101 ± 0.00020 (0.00064, 0.00138)	0.00077 ± 0.00024 (0.00046, 0.00156)	0.00054 ± 0.00018 (0.00026, 0.00082)	24.187 (0.000)

Figure 5 shows the distribution of the readings and differences can be noticed clearly where the peak was varied from one to another.

Bonferroni post-hoc tests were performed to uncover particular differences between the file systems after the significant ANOVA results, as shown in Table 3. Significantly, every comparison revealed notable variations in the Mean Differences (actual debris extrusion). RACE EVO extruded much more debris than Mtwo (p = 0.0044), while ProTaperNext extruded debris significantly more than both RACE EVO (p = 0.0019) and Mtwo (p < 0.0001). The study's goal of determining variations in debris extrusion be-

DOI: doi.org/10.15218/edj.2025.22

tween the systems was achieved by these post-hoc results, which show that Mtwo produced the least amount of apical debris, RACE EVO was in the middle, and ProTaper Next produced the most. Figure 6 shows the pairwise comparison for the differences in reading values, and the significant differences were labeled with the (*) symbol.

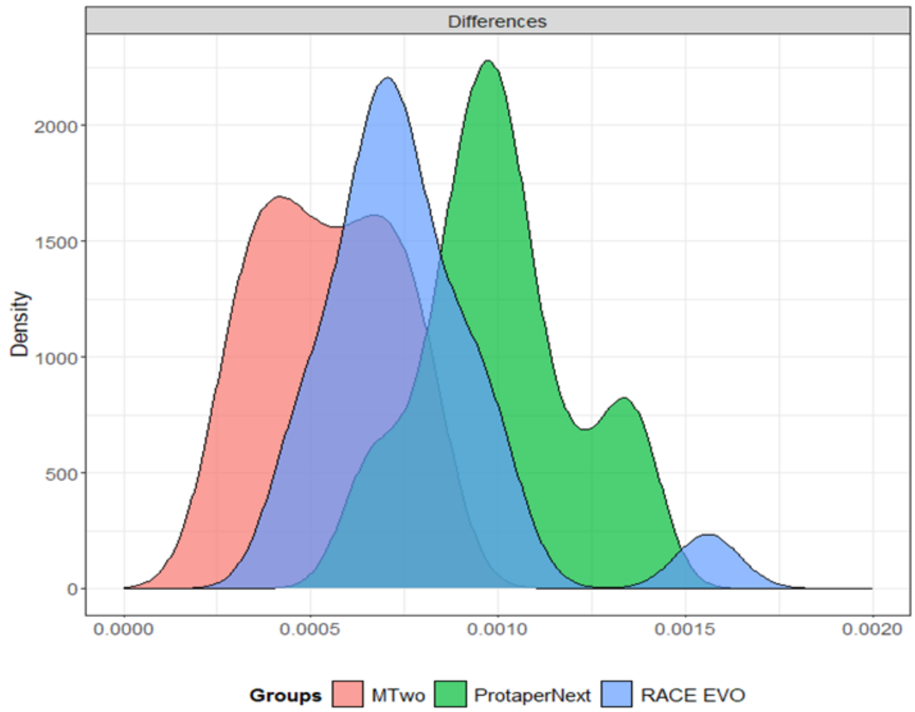

Figure 5. Density plot exploration of the readings with respect to instruments

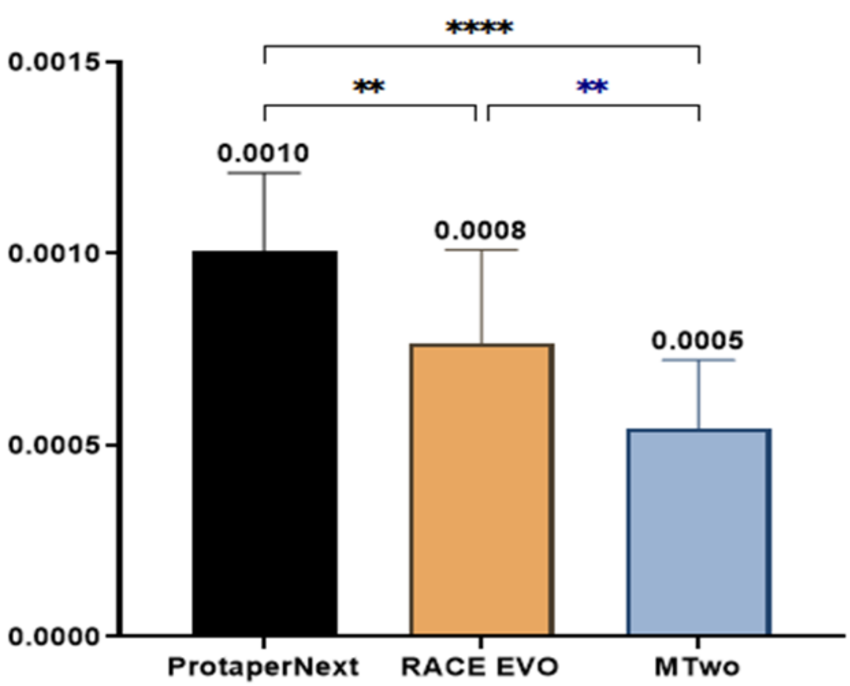

Figure 6. Error-bar chart plot for the differences reading at each group

Table 3. Bonferroni pairwise comparisons between instrumentation systems for empty, vials debris, and mean differences

Readings	Groups		Mean Difference (I-J)	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
Differences	Protaper-Next	RACE EVO	0.0002	0.0019	0.0001	0.0004
		MTwo	0.0005	0.0000	0.0003	0.0006
	RACE EVO	MTwo	0.0002	0.0044	0.0001	0.0004

DISCUSSION

This study sought to compare and evaluate how three rotary file systems—ProTaper Next, RACE EVO, and Mtwo—generated extrusion of debris apically in the process of canal instrumentation using distilled water as an irrigant to isolate the variable of file design and its direct impact on debris extrusion, without the confounding factor of irrigant precipitation.[19]

ProTaper Next produced the highest amount of debris, followed by RACE EVO, and Mtwo, showing the least extrusion. Results showed statistically significant variations among the systems ($p < 0.001$). These results draw attention to how instrument design, especially cross-sectional geometry and flute arrangement, may affect debris extrusion. The significance of file design has been concluded by many studies in influencing the quantity of debris extruded apically.[2,14,15]

Endodontic files with smaller cross-sectional areas tend to cut more effectively. According to Researchers, the wider the space between the file and canal walls, the more the coronal displacement of debris during instrumentation.[8]

While files with progressively changing flute angles show two main advantages—first, they more effectively direct debris upward out of the canal, and second, they lower the risk of the file being drawn too deeply into the root canal space—files maintaining uniform helical angles tend to trap debris.[9]

With its S-shaped cross-section and progressive taper, the Mtwo system proved better in reducing apical extrusion. This design lessens the piston-like effect caused by forces apically and helps to efficiently remove coronal debris. Mtwo's lower extrusion of debris due to its deep flutes, progressive pitch, and less contact with canal walls.[10] Its alternating pitch and higher flute volume—help maximize chip space and lower screw-in forces, so minimizing apical compaction of debris.[11,12]

ProTaper Next was associated with the highest degrees of debris extrusion. Its rectangular cross-sectional geometry minimizes the chance for dentin chip evacuation, despite increasing cutting efficiency and file strength. A piston-like movement might be behind pushing the debris apically.[13] RACE EVO, on the other hand, had a moderate level of debris extrusion. Though it has similar characteristics to its predecessor, it also introduces improvements such as asymmetric rotational motion that may enhance debris evacuation effectiveness. Nonetheless, its triangular cross-section provides less chip space than Mtwo, which may explain its relatively increased amount of extrusion. File systems with triangle cross-sections and greater core masses more often than not provide elevated apical pressure, increasing debris extrusion.[16]

The Bonferroni post-hoc analysis indicated significant differences in all pairwise comparisons, especially between ProTaper Next and Mtwo ($p < 0.0001$). This highlights the importance of file geometry, flute design, and motion kinematics in influencing debris extrusion. Research showed that files with S-shaped cross-sections have contributed to minimizing debris extrusion when compared to file systems with either rectangular or triangular cross-sections, thus supporting the current findings.[17]

Complications of debris extrusion include flare-ups, postoperative discomfort, and inflammation;[18] that is why, being a key concern, and every aspect of the process, mechanical and biological,

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is crucial to be optimized. Hence, it is fundamental to apply a filing apparatus that enables the provision of minimal extrusion, particularly when a periapical lesion or necrotic pulps are involved.

Limitations

Standardization of the anatomy and canal curvature was at its utmost in this study; nonetheless, extracted teeth cannot be an optimal depiction of a viable tooth. Further, anatomical variations are still a challenging factor that affects the pattern with which debris is practically extruded. Upcoming studies using in vivo teeth and micro-CT as an investigation can explain extrusion mechanisms and verify their application in clinical circumstances.

One drawback of distilled water as an irrigant is that it can not resemble the viscosity and flow patterns of irrigants applied in daily clinical practice, such as EDTA or NaOCl; however, it can prevent crystalization interference and chemical interactions. Variable flow and deformation properties of the commonly used solutions influence patterns of extrusion and instrumentation debris mobilization.[19] Surface tension and tissue-dissolving features of NaOCl vary from distilled water, which alter debris mobilization during preparation of the canal.

CONCLUSION

this study verifies the significant impact of file system structure in handling debris extruded apically. the most agreeable result was achieved by Mtow's performance with its potent debris evacuating features. These outcomes reinforce the idea of visualizing cross-sectional geometry as a fundamental parameter in the selection of file systems to minimize complications and better the results.

AKNOWLEDGMENTS

I would like to acknowledge the Department of Conservative Dentistry for providing a supportive academic environment. I am grateful to the Head of Department for encouragement and continued support throughout the study. I also thank the staff of the Hawler Medical University laboratories for their technical assistance and access to facilities essential for sample preparation and analyses. Finally, I extend my deepest appreciation to my family for their patience, encouragement, and unwavering support during the course of this work.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest related to this work.

FUNDING

The authors received no financial support for the research, authorship, and/or publication of this article.

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