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ORIGINAL ARTICLE

Comparison of debris removal efficiency of different endodontic file systems

ABSTRACT

Aim: *The aim of this study was to compare 4 different NiTi endodontic file systems [ProTaper Next (PTN), ProTaper Ultimate (PTU), VDW.Rotate (VR), and XP-Endo Shaper (XPS)] in terms of their instrumentation time (IT) and material removal capacity using standardized transparent acrylic root canal blocks (TABs).*
Methods: *A total of 80 standardized TABs with canals of 17 mm length, a constant taper of 2%, and a curvature of 30 degrees were used. The root canals were randomly assigned to 4 experimental groups (n = 20 each), each of which used one of the tested file systems. All the instrumentation procedures were performed by a single operator following manufacturers' protocols using a torque-controlled endodontic motor. The weight of each TAB was measured before and after instrumentation using a precision scale, and the percentage of material loss was calculated. IT was also recorded using a digital stopwatch. Data was analyzed using one-way ANOVA, Kruskal-Wallis test, and Pearson correlation, with a significance level set at $P < 0.05$.*
Results: *XPS demonstrated the highest material loss, significantly greater than PTN and VR ($P < 0.001$), while VR exhibited the most conservative material removal. XPS also showed the shortest IT, whereas PTU exhibited the longest ($P < 0.001$). A moderate positive correlation was found between IT and material loss ($r = 0.579$, $P < 0.001$).*
Conclusions: *Endodontic file systems differ significantly in shaping efficiency and dentin preservation. The XPS offered superior time efficiency but removed more material, while VR preserved dentin more effectively. These findings may guide clinicians in selecting endodontic file systems based on clinical priorities. Future studies using natural teeth are recommended to validate these findings.*

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Introduction

In contemporary endodontics, nickel–titanium (NiTi) endodontic files have revolutionized root canal instrumentation procedures. Compared to manual techniques, these systems facilitate the creation of more consistent tapered preparations, thereby enhancing treatment efficacy. In addition, they contribute to increased operator efficiency by reducing fatigue and shortening procedure time, which in turn improves patient comfort (1,2). The mechanical capabilities of endodontic file systems allow for efficient canal preparation in less time, resulting in both time and labor savings. Consequently, these advantages have made this instrumentation an indispensable component of modern endodontic practice (3).

NiTi endodontic file systems differ considerably in terms of their NiTi alloy composition, cross-sectional geometry, taper design, and kinematics. For instance, ProTaper Next (PTN) (Dentsply Maillefer, Ballaigues, Switzerland) is manufactured from M-Wire alloy and features a variable taper with an off-centered rectangular cross-section, a configuration designed to reduce contact points within the canal and minimize instrument fatigue (3,4). In contrast, the XP-Endo Shaper (XPS) (FKG Dentaire, LaChaux-de-Fonds, Switzerland) is a single-file system made from MaxWire alloy, which exhibits phase transformation properties. While in a narrow martensitic form at room temperature, it transitions to an expanded semi-circular shape with an approximate 0.04 taper at body temperature (~35 °C) due to its shape memory effect (5). This dynamic behavior enables the file to adaptively contact more canal walls while maintaining high flexibility (6). The VDW.Rotate (VR) (VDW, Munich, Germany) system comprises files with small tapers (e.g. 0.04 and 0.05) and incorporates an adaptive S-shaped cross-section. This design prioritizes dentin preservation in narrow canals and facilitates effective debris removal (7). Moreover, newer systems such as ProTaper Ultimate (PTU) (Dentsply Maillefer) utilize advanced thermally treated “gold” NiTi alloys, offering enhanced flexibility and improved resistance to cyclic fatigue (8).

In addition to mechanical instrumentation, chemical debridement constitutes a fundamental component of root canal treatment. The complex anatomy of the root canal system often harbors residual tissue, bacteria, and smear layer that cannot be completely eliminated by instrumentation alone. Therefore, the irrigation phase plays a pivotal role in achieving optimal disinfection and cleanliness of the canal system (9). Effective irrigation enhances the removal of organic and inorganic debris, aids in smear layer elimination, and improves the penetration of intracanal medicaments and sealers (9). Recent studies (15,16) have highlighted the importance of both irrigant activation and temperature in enhancing debridement efficacy. Penukonda et al.(10) demonstrated that activation systems such as Ultra-X and XP-Endo Finisher significantly improve smear layer removal, suggesting that mechanical agitation complements chemical irrigants in cleaning complex canal anatomies. Similarly, Abdellatif et al. (11) reported that using Dual Rinse HEDP at elevated temperatures significantly improved bovine pulp tissue dissolution, underscoring the relevance of temperature-controlled irrigation protocols. These findings emphasize that root canal instrumentation is not solely dependent on the file system used, but also on the adjunctive irrigation strategy implemented, which ultimately affects clinical outcomes.

Technological differences among the NiTi file systems have a direct impact on 2 critical parameters: instrumentation time (IT) and material removal (12). Single-file systems like the XPS tend to reduce IT due to fewer file changes, unlike multi-file systems such as PTN, PTU, and VR (13,14). Moreover, the file’s taper and cross-sectional area are key determinants of how much dentin is removed; larger tapers typically result in more extensive tissue removal, which may compromise root strength (15). In contrast, conservative designs with minimal taper are aligned with minimally invasive endodontic principles and help preserve root dentin. Cross-sectional geometry and motion type also influence shaping efficacy; for example, S-shaped cross-sections improve debris removal, while thermomechanically adaptive designs like that of XPS enhance wall contact. Clinically, shorter ITs are advantageous in managing pediatric or anxious patients, while preserving dentin is essential for maintaining long-term structural integrity and reducing the risk of root fracture (15,16). Therefore, selecting a file system that balances efficiency with dentin conservation is crucial in endodontic practice.

Considering these factors, it becomes evident that comparative evaluations of NiTi endodontic file systems are of significant importance. Although several studies (10,11,17) have researched individual file systems or performed pairwise comparisons (such as XPS versus PTN or VR versus ProTaper Gold) (13,14,17) comprehensive evaluations directly comparing XPS, PTN, PTU, and VR in terms of both IT and dentin preservation remain limited in the current literature. Accordingly, the aim of this study was to systematically compare the time efficiency and material removal performance of these four file systems, thus addressing the current gap in the literature. The null hypothesis tested in this study is that there is no significant difference among the XPS, PTN, PTU, and VR file systems in terms of IT and the amount of material removed from transparent acrylic blocks (TABs).

Materials and Methods

Sample Selection and Standardization

As this was an in vitro study involving no human or animal subjects, ethical approval was not required. The sample size was calculated using G*Power 3.1 (Heinrich Heine University, Düsseldorf, Germany), assuming a significance level (α) of 0.05, a power (1–β) of 0.80. The analysis indicated that a minimum of 19 samples per group were required to achieve adequate statistical power.

A total of 80 TABs (Dentsply Maillefer) with simulated single root canals were used. All the root canals were approximately 17 mm in length and had a 2% constantly increasing taper with a curvature of 30 degrees. The TABs were inspected using a stereomicroscope (Stemi 508, Zeiss, Oberkochen, Germany) to ensure the absence of manufacturing defects or deformities. The root canals were initially scouted with a size 10 K-type file until its tip was visible at the apical foramen, and the working length (WL) was set 0.5 mm shorter. Before the instrumentation, a glide path was established with a #15 K-file to the WL for each root canal.

Instrumentation Protocol

The TABs were then randomly assigned to 4 groups (n = 20) based on the used NiTi file systems PTN, PTU, VR, and XPS.

- PTN group: Glide path was prepared using a ProGlider file after confirmation with a size 15 K-file (Mani Inc., Tochigi, Japan). Instrumentation was initiated with X1 (17/.04), followed by X2 (25/.06), and completed with X3 (30/.07). All files were operated in continuous rotation at 300 rpm and 2 Ncm torque.
- PTU group: Glide path was prepared using the Slider (16/.02) file. Instrumentation was performed using the Shaper (20/.04), Finisher F1 (20/.07), Finisher F2 (25/.06), and Finisher F3 (30/.09). All files were operated in continuous rotation at 400 rpm and 4.0 Ncm torque.
- VR group: Glide path was prepared using VR 15/.04. Instrumentation was performed with VR 20/.05, 25/.04, and 30/.04 files. All files were operated in continuous rotation at 350 rpm and 2.0 Ncm torque.
- XPS group: Glide path was confirmed with a size 15 K-file. Instrumentation was performed using a single XPS file (30/.01). The file was operated in continuous rotation at 800 rpm and 1 Ncm torque. In this group, the TAB were immersed in a water bath at 35 °C to simulate intracanal conditions and ensure optimal performance of the XPS

file. At this temperature, the file undergoes a phase transformation from martensite to austenite, resulting in controlled expansion. This transformation facilitates a consistent preparation taper of 4% along the entire length of the root canal.

All instrumentation procedures were carried out by a single experienced operator, who is a certified endodontist with more than 5 years of clinical experience in the field, in accordance with the manufacturers' protocols using a torque-controlled endodontic motor (X-Smart Plus, Dentsply Sirona, Ballaigues, Switzerland). During the procedures, the TABs were stabilized using modeling wax (Polywax, Bilkim Co. Ltd., Istanbul, Türkiye) to ensure consistent positioning and prevent displacement.

Each canal was prepared up to the final file recommended for that system, and the instrumentation was performed with distilled water irrigation delivered using a 30-gauge side-vented needle (EndoArt, Inci Dental, Istanbul, Türkiye). The volume of irrigant was standardized across all samples (10 mL per canal). After preparation, each canal was rinsed with 5 mL of distilled water and dried with paper points.

Weight Measurement and Material Loss Calculation

Before instrumentation, each TAB was individually weighed using a precision analytical balance (XB 220A; Kunz Precisa, Zofingen, Switzerland). After instrumentation and irrigation, the TABs were rinsed, dried, and reweighed using the same balance under identical environmental conditions. The percentage of material loss was calculated using the formula:

Material Loss (%) = (Initial Weight - Final Weight) / Initial Weight × 100

Time Measurement

The total IT was measured using a digital stopwatch (Neval Digital Stopwatch, Istanbul, Türkiye) operated by an independent observer. The timer was started when the shaping file entered the canal and stopped once it was fully removed. Only the time during which the shaping file was actively engaged within the canal was included. Irrigation, patency checks, and drying steps were excluded from the time calculation to ensure standardization.

Statistical Analysis

All data were statistically analyzed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). The normality of data distribution was assessed using the Shapiro-Wilk test. One-way ANOVA was used for normally distributed variables (e.g., instrumentation time), while the Kruskal-Wallis test was employed for non-normally distributed variables (e.g., material loss in the XP-Endo Shaper group). Post-hoc pairwise comparisons were conducted with Tukey's or Dunn's tests as appropriate. A Pearson correlation analysis was performed to evaluate the relationship between preparation time and material loss. Statistical significance was set at $P < 0.05$.

Results

For each group, the IT (min) and percentage of weight loss were calculated as mean ± standard deviation (SD). Normality was assessed using the Shapiro-Wilk test. IT showed normal distribution across all groups, while the percentage of weight loss in the XPS group did not follow a normal distribution ($p = 0.014$).

Weight Loss

The Kruskal-Wallis H test showed significant differences in the percentage of weight loss among groups ($H = 42.685$, $df = 3$, $P < 0.001$). Pairwise comparisons using the Mann-Whitney U test with Bonferroni correction ($\alpha = 0.0083$) revealed that the XPS group was significantly different from both PTN (Adj. Sig. = 0.000) and VR (Adj. Sig. = 0.001). However, the difference between XPS and PTU was not statistically significant after adjustment (Adj. Sig. = 0.080). Pairwise comparisons with Bonferroni correction are shown in

Table 1
Tukey HSD post-hoc results for preparation time.

Groups	Mean Difference ± SE	p-value
PTU vs. PTN	2.88 ± 0.65	<0.001 *
PTU vs. VR	10.81 ± 0.65	<0.001 *
PTU vs. XPS	21.11 ± 0.65	<0.001 *
PTN vs. VR	7.93 ± 0.65	<0.001 *
PTN vs. XPS	18.23 ± 0.65	<0.001 *
VR vs. XPS	10.30 ± 0.65	<0.001 *

** Statistically significant at P < .05.*

Table 2
Pairwise comparisons between endodontic file systems (Mean Differences ± Std. Error, Bonferroni-adjusted p-values).

Groups	Mean Difference ± SE	Adjusted p-value
XP vs. PTU	19.48 ± 7.35	0.080
XP vs. VDW	28.38 ± 7.35	0.001 *
XP vs. PTN	42.45 ± 7.35	0.000 *
PTU vs. VDW	–8.90 ± 7.35	1.000
PTU vs. PTN	22.98 ± 7.35	0.018 *
VDW vs. PTN	14.08 ± 7.35	0.554

** Statistically significant (P < .05, Bonferroni-adjusted)*
Note: *Mean differences represent the score of Group A minus Group B.*

detail in Table 2. A significant difference was also found between PTU and PTN (Adj. Sig. = 0.018), whereas no significant differences were observed between PTU and VR or VR and PTN. According to the results shown in Table 3, a moderate positive and statistically significant correlation was found between preparation time and weight loss ($r = 0.579$, $P < 0.001$).

Instrumentation Time
A one-way ANOVA was performed to evaluate differences in IT among groups. The analysis revealed a statistically significant difference ($P < 0.001$). Tukey HSD post-hoc test results are summarized at Table 1. The PTU group demonstrated a significantly longer IT compared to all other groups ($P < 0.001$). Conversely, the XPS group exhibited the shortest IT, which was statistically significantly different from all other groups ($P < 0.001$).
A positive correlation between IT and material loss was observed.

Discussion

In this study, different NiTi endodontic file systems were compared in terms of their IT and material removal capacity. Standardized canal instrumentation was performed using TABs to evaluate the impact of each system's technological design on shaping efficiency. The findings suggest that the structural and technological differences among the systems may lead to clinically significant outcomes.

Table 3
A moderately positive and statistically significant correlation was shown between time and weight loss.

Variable 1	Variable 2	Correlation Coefficient (r)	p-value
Time	Weight Loss	0.579	<0.001

The performance of NiTi endodontic file systems is directly influenced by their metallurgical composition and geometric design. In this context, the structural and technological characteristics of the systems compared in this study demonstrated notable differences in terms of IT and material removal capacity. PTN features a variable taper and an off-centered rectangular cross-section. It is manufactured using M-Wire, a heat-treated NiTi alloy, which enhances flexibility and reduces the risk of file fracture (18,19). PTU is a multi-file system in which each file is fabricated from a distinct proprietary alloy (M-Wire, Gold, Blue NiTi). With its parallelogram-shaped cross-section and a maximum flute diameter limited to 1 mm, the system aims to balance cutting efficiency and flexibility. Due to its R-phase crystalline structure, it offers superior flexibility compared to previous generations (8,20). VR comprises three files and incorporates an adaptive S-shaped cross-section that closely follows the natural root canal anatomy. The use of a newly developed heat-treated NiTi alloy improves the system's flexibility and fracture resistance. Additionally, the file's cross-section is designed with a central offset, which enhances debris removal and cleaning efficiency (17). XPS is a single-file system characterized by highly dynamic thermomechanical behavior. Made from MaxWire alloy, the file is in the martensitic phase at room temperature and transforms into the austenitic phase within the canal, expanding into a semi-circular shape upon exposure to body temperature (6). During rotation, it forms 6 cutting edges due to its booster tip design, allowing the file to expand from an initial ISO size 15 with a 0.01 taper to approximately ISO size 30 with a 0.04 taper. This structural adaptability enables the file to make extensive contact with canal walls and perform effective shaping, particularly in oval and irregularly shaped canals (6,21).
Considering their distinct design philosophies, the 4 systems were purposefully selected to encompass a wide spectrum of contemporary endodontic instrumentation approaches. PTN was chosen based on its well-documented clinical efficacy and widespread adoption, serving as a reference multi-file system characterized by M-Wire technology and an off-centered design that collectively enhances shaping efficiency and file flexibility (18,19). PTU and VR, as relatively recent advancements in multi-file instrumentation, were included owing to their sophisticated metallurgical properties and minimally invasive design concepts (17,20). It was aimed to evaluate these file systems that aim to increase dentin protection with these features. In contrast, the XPS was incorporated for its distinctive thermomechanical properties and capacity to achieve complete canal preparation using a single file, enabling direct comparison with conventional multi-file systems (6).
Moreover, in order to standardize apical preparation across all groups, files corresponding to a final apical size of ISO 30 were selected. This decision was driven by the fact that XPS offers a fixed apical diameter of 30 as part of its design, thereby necessitating the use of size 30 files in the other systems to ensure consistency and comparability in shaping outcomes.
In terms of dentin removal, systems with a conservative design, such as VR, generally tend to preserve more root canal structure by removing less tissues. This finding is supported by the study of Piț et al. (17) where VR exhibited the lowest material removal among the evaluated systems. In contrast, the XPS, due to its expanding geometry and adaptive design, increases the canal volume and the number of contacted canal walls. Azim et al.

(14) demonstrated that XPS removed significantly more dentin than Vortex Blue, particularly in the coronal and middle thirds. Similarly, Poly et al. (13) found that repeated activation of the XPS file, performed 25 times, resulted in greater dentin removal in the coronal third compared to the PTN X3 instrument. In a study (22) XPS was shown to remove more dentin and achieve larger canal wall preparation compared to PTN, especially at multiple root levels, like previous findings in literature. Consistent with these findings, our study also showed that XPS exhibited the highest amount of dentin removal among the tested systems, particularly due to its expanding file design and enhanced wall contact, while VR removed the least amount of material, likely owing to its conservative cross-sectional architecture.
Based on the findings of our study, the null hypothesis was also rejected in terms of the amount of material removed from the TABs, given the significant variability in shaping outcomes across the tested systems. In multi-file systems such as PTN, the increased number of shaping steps generally results in longer ITs. In contrast, the single-file XPS can shape the canal in a shorter period due to its reduced number of procedural steps and adaptive design. In a micro-CT study by Poly et al. (13) the mean IT for XPS was reported as approximately 90 ± 7 sec, while PTN X3 required about 112 ± 9 sec. Similarly, in an in vitro study by Piț et al. (17) TruNatomy showed the shortest IT (14 sec), followed by VR (~40 sec), Reciproc Blue (~53 sec), and ProTaper Gold (~63 sec). VR was found to require significantly less time compared to the four-step ProTaper Gold sequence. These findings suggest that, in general, systems using fewer and finer files tend to reduce the overall procedure time, whereas multi-step protocols are associated with longer shaping durations. In our study, a similar trend was observed in accordance with the existing literature. The significantly longest IT was recorded in the PTU group, which utilizes a multi-file system, whereas the XPS group, employing a single-file approach, demonstrated the shortest IT in a statistically significant manner. In the light of the findings of our study the null hypothesis was rejected with respect to IT, as statistically significant differences were observed among the file systems evaluated.
The differences in IT and dentin removal are clinically significant. The use of NiTi endodontic file systems can enhance treatment efficiency by reducing the duration of canal shaping procedures, thereby facilitating the process for both the clinician and the patient (23). Shorter ITs are particularly advantageous in pediatric patients or individuals with limited cooperation, contributing to increased comfort and improved treatment outcomes. On the other hand, the amount of residual dentin is critically important for root fracture resistance. Previous studies have demonstrated that instrumentations preserving more dentin are associated with a reduced risk of root fractures (24–26). Therefore, in selecting NiTi endodontic file systems, a balance must be maintained between effective disinfection and canal enlargement while preserving as much sound dentin as possible. In this regard, systems that optimize efficiency without causing unnecessary structural loss are essential for long-term clinical success.
In our study, the XPS demonstrated significantly greater dentin removal compared to the other systems evaluated. This finding may be attributed to several key design features of the file. The adaptive expansion capability of its MaxWire alloy allows the file to increase both its diameter and taper from an initial 0.01 to approximately 0.04 at body temperature, enabling it to contact canal surfaces that are typically untouched by conventional files (21). Additionally, its booster tip design, characterized by a tapered shape and 6 cutting edges, facilitates efficient material removal across broader areas through helical motion. Azim et al. (14) also reported that XPS exhibited low untouched wall percentages and produced more extensive canal preparations. Furthermore, the application of extended activation time has been shown to enhance its shaping performance (13). Collectively, these factors support the observation that XPS may

operate more aggressively within the canal. Although various irrigants (e.g. sodium hypochlorite, EDTA, and chlorhexidine) are widely used in clinical endodontics for their antimicrobial and tissue-dissolving effects, distilled water was chosen in the present study to avoid the potential confounding influence of these chemically active agents on TABs. Prior studies (27,28) have shown that such irrigants may alter the physical properties of synthetic materials, potentially compromising the integrity of simulated canals and leading to inaccurate evaluation of instrumentation performance. Thus, the use of distilled water provided a controlled environment and maintained the standardization necessary for valid comparisons among instrumentation systems.

The use of TABs offers significant advantages in experimental endodontic research by providing standardized canal dimensions, shapes, and curvatures, while eliminating the risk of biological contamination. Their transparency allows for real-time visualization of instrumentation, facilitating more immediate detection of canal morphology changes compared to natural dentin. Moreover, the ability to define canal curvature and diameter mathematically ensures high reproducibility and enables direct comparison between different files or instrumentation protocols under consistent conditions (29).

Despite their advantages, the use of TABs in endodontic research is associated with notable limitations. One major concern is the potential softening of the acrylic material due to the heat generated by rotary files during instrumentation. This softening may lead to the file embedding into the acrylic and increase the risk of file separation. Such effects are partly due to the mechanical and thermal properties of acrylic, which differ significantly from natural dentin - TABs typically have approximately half the hardness of human dentin and markedly distinct thermal conductivity. Furthermore, the canal configurations in TABs are often uniform and simplified, lacking the anatomical complexity and variability encountered in clinical cases (30,31). As a result, instrumentation outcomes observed in TABs may not accurately reflect file performance in natural root canals. Therefore, caution is warranted when extrapolating findings from acrylic-based simulations to real clinical scenarios. These results contribute to clinical decision-making in selecting endodontic file systems according to specific procedural needs.

In addition, the fact that all instrumentation procedures were performed by a single human operator constitutes an inherent limitation of the study. Human-dependent techniques are subject to intra-operator variability, including factors such as differences in applied pressure, motion consistency, and tactile feedback. Unlike automated or robotic systems that offer high levels of standardization and reproducibility, manual instrumentation introduces an element of subjectivity, which may influence the uniformity and comparability of the results.

Conclusion

Within the limitations of this in vitro study, it can be concluded that the evaluated NiTi endodontic file systems demonstrated significant differences in both IT and material removal. The XPS exhibited the shortest IT and the highest material removal, likely due to its single-file design and thermomechanical adaptability. In contrast, PTU required the longest IT, while VR was the most conservative in terms of material removal. These results underscore the importance of choosing an endodontic file system that balances shaping efficiency and dentin preservation for optimal clinical outcomes.

Author Contributions

K.E. designed the study; D.E. and A.D. contributed to data collection and performed statistical analysis; Y.E.Ç., Z.Ç. and O.P.B. drafted the manuscript; A.M.P. and K.E. critically revised the article for important intellectual content. All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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