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Effect of different canal shaping and obturation techniques on retreatment efficacy: An in vitro study

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Purpose: This study aimed to evaluate the effect of different canal shaping and obturation techniques on retreatment efficacy by analyzing the weight of removed filling material, retreatment time, and surface area reduction.

Methods: Eighty standardized acrylic resin blocks were shaped using four endodontic file systems [ProTaper Next (PTN), ProTaper Ultimate (PTU), VDW Rotate (VR), and XP-endo Shaper (XPS)] and obturated with either single-cone (SC) or continuous wave compaction (CWC), forming eight experimental groups (n=10). All samples were retreated using a single-file system. The amount of removed material was measured with a precision balance, time was recorded in seconds, and surface cleanliness was assessed using ImageJ software. Data were analyzed using the Kruskal–Wallis test followed by Bonferroni-adjusted pairwise comparisons.

Results: Statistically significant differences were found among groups for all parameters. XPS/SC and PTN/SC removed significantly more filling material than PTU/CWC and XPS/CWC. Retreatment times were significantly longer in XPS/SC and PTN/SC, and significantly shorter in PTU/CWC and XPS/CWC. For surface area reduction, PTU/CWC and XPS/CWC achieved the highest values, with CWC groups generally outperforming SC groups in cleanliness. Weight reduction correlated positively with time, while time correlated negatively with surface area reduction.

Conclusion: Retreatment efficacy is significantly influenced by the initial shaping and obturation technique. CWC generally resulted in shorter retreatment times and greater surface cleanliness, whereas SC groups tended to have greater filling removal by weight.

Keywords: Obturation; retreatment; root canal treatment; shaping.

Introduction

Root canal treatment (RCT) aims to restore and maintain oral health by eliminating infection and preserving the tooth's function, aesthetics, and patient comfort in individuals affected by pulp or periapical disease due to trauma or carious lesions (1). One of the principal causes of RCT failure is the continued presence of intraradicular infection (2). Thus, achieving complete removal of previously placed

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fillings is fundamental to the retreatment process. Nonsurgical endodontic retreatment is often required when primary RCT fails, with reported failure rates ranging from 14% to 22% depending on case complexity, presence of missed canals, and operator skill (3). During endodontic retreatment, apical extrusion of obturation residues and debris may lead to postoperative discomfort and delayed healing. Thus, using a shaping technique that minimizes extrusion can help reduce such complications (4).

Recent advancements in metallurgy and file design (e.g., heat-treated NiTi alloys and reciprocating motion) have enhanced the flexibility and cyclic fatigue resistance of retreatment files, thereby improving their ability to negotiate complex canal anatomies (5). Nickel-titanium (NiTi) alloy-based motor-driven files, available in a variety of designs and taper configurations, have been widely adopted for effective cleaning and shaping of the root canal system. These files are engineered to facilitate coronal transportation of dentinal debris, which contributes to minimizing the apical extrusion of fillings during canal shaping (6).

The type of obturation technique and sealer used in the primary RCT significantly influences the ease of removal during retreatment and the amount of residual material left on the canal walls. Athkuri et al. (7) reported that root canals initially obturated using thermoplasticized techniques exhibited a significantly greater percentage of residual filling following retreatment procedures. In a recent systematic review and meta-analysis, Olivieri et al. (8) concluded that the obturation technique and sealer employed during primary RCT may significantly influence retreatment outcomes, particularly regarding the efficiency of filling removal and the amount of residual material remaining on canal walls.

Recently introduced as part of a contemporary instrumentation approach, the Perfect Super System Retreat ONE (Shenzhen Perfect Medical Instruments Co., Ltd., Shanwei, China) been specifically designed for non-surgical root canal retreatment procedures. This system represents a novel advancement in endodontic retreatment by offering enhanced cutting efficiency and flexibility, particularly in curved and previously filled canals. According to manufacturer documentation, the Retreat ONE file enables effective removal of gutta-percha and root canal sealers with minimal stress on the instrument, supporting safer and faster retreatment workflows. Its design aligns with the principles of minimally invasive endodontics, aiming to preserve dentin while ensuring thorough debridement of the root canal system (9).

To explore the impact of shaping and obturation techniques on retreatment efficacy, four widely used file systems were selected in this study: ProTaper Next (Maillefer Ins., Ballaigues, Switzerland) and ProTaper Ultimate (Dentsply Sirona, Ballaigues, Switzerland), which are multi-file rotary systems with progressive tapers; VDW Rotate (VDW GmbH, Munich, Germany), a heat-treated NiTi system optimized for minimally invasive shaping; and XP-Endo Shaper (FKG Dentaire Sàrl, Le Crêt-du-Locle, Switzerland), a single-file system designed to adapt to canal morphology due to its shape-memory properties (10). For obturation, the Single-Cone (SC) technique and Continuous Wave Compaction (CWC) method were used to represent two common yet distinct approaches. These combinations were chosen to reflect a range of contemporary clinical practices and to evaluate how different initial protocols affect retreatment outcomes

Therefore, this study aimed to compare the impact of different shaping and obturation techniques on retreatment efficacy by evaluating material removal, surface cleanliness, and procedural time in a standardized in vitro model. The findings of this study are expected to contribute to evidence-based decision-making by guiding clinicians toward more effective and predictable retreatment protocols in nonsurgical endodontics. The null hypothesis tested was that the type of root canal shaping system and obturation technique would not significantly influence the amount of removed filling material, retreatment time, or canal surface cleanliness during retreatment procedures.

Materials and Methods

The manuscript of this laboratory study has been written according to Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines (11) (Fig. 1).

Sample Selection and Standardization

Since this study was conducted entirely in vitro using standardized training acrylic blocks (TABs), with no involvement of human or animal subjects, ethical approval was not required. No human or animal tissues or biological samples were used.

The sample size was determined using GPower 3.1 software (Heinrich Heine University, Düsseldorf, Germany), based on a significance level of α=0.05, a statistical power of 80% (1–β), and an assumed effect size of f=0.50, which corresponds to a large effect according to Cohen's conventions. This value was selected based on previous studies that reported substantial intergroup differences in retreatment efficacy using standardized models. (7) The analysis indicated that a minimum of 9 samples per group would be sufficient to achieve adequate power; therefore, 10 samples were included in each group, totaling 80 TABs (Dentsply Maillefer, Ballaigues, Switzerland). Experimental groups



Fig. 1. Preferred reporting ıtems for laboratory studies in endodontology (PRILE 2021) flow chart.

were categorized based on 2 variables: The type of shaping system (PTN, PTU, VR, and XPS) and the obturation technique used (SC or CWC).

The TABs were approximately 17 mm in length, with a 2% taper and a curvature of 30°, simulating single-rooted canal morphology. All the TABs were examined under a stereomicroscope (Stemi 508, Zeiss, Oberkochen, Germany) to identify manufacturing defects or deformations, and only defect-free TABs were included in the study. Working length (WL) was established by inserting a #10 K-file until it was visible at the apical foramen and subtracting 0.5 mm. Glide path preparation was performed using a #15 K-file in all canals.

Since standardized TABs were used, sterilization was not applicable; all specimens were handled using clean gloves and stored in dry conditions prior to use.

Shaping Procedure

The TABs were randomly assigned to 4 main groups according to the shaping system used: PTN, PTU, VR, and XPS. All procedures were performed by two endodontists with at least 5 years of clinical experience, strictly following the manufacturers' instructions. For stabilization, the TABs were embedded in modeling wax (Polywax, Bilkim, Istanbul, Türkiye).

PTN group: The glide path was prepared using the ProGlider file, followed by sequential use of X1 (17/.04), X2 (25/.06), and X3 (30/.07) files at 300 rpm with 2 Ncm torque.

PTU group: The glide path was created with the Slider file (16/.02), followed by Shaper (20/.04), Finisher F1 (20/.07), F2 (25/.06), and F3 (30/.09) files in sequence, operated at 400 rpm and 4 Ncm torque.

VR group: The glide path was prepared using VR 15/.04, followed by VR 20/.05, 25/.04, and 30/.04 files, operated at 350 rpm and 2 Ncm torque.

XPS group: The glide path was verified using a K-file, and then a single XPS file (30/.01) was used at 800 rpm and 1 Ncm torque. This group was shaped in a 35 °C warm water bath to simulate body temperature conditions.

Each canal was irrigated with 10 mL of distilled water during shaping, followed by a final rinse with 5 mL of distilled water. The canals were then dried using sterile paper points.

Obturation Procedure

Twenty TABs prepared with each shaping system were further divided into 2 subgroups based on the used obturation technique (n=10) (SC and CWC):

SC group: The canals were obturated using the conventional SC technique. Master cones with appropriate tapers were selected for each system: X3 for PTN, F3 for PTU, and 30/.04 cones for both VR and XPS groups. The cones were severed at the canal orifice using the Fast Pack Pro device (200 °C), and then vertically condensed using a #70 hand plugger.

CWC group: All samples were obturated using the Fast Fill device (Eighteeth, Changzhou, China) with the thermoplastic injection technique. The obturation was performed in 3 segments, progressing from the apical to the coronal third. After each segment, vertical compaction was applied using appropriately sized hand pluggers to ensure homogenous filling.

The SC technique was chosen instead of cold lateral condensation (CLC) to reduce technique sensitivity and operator-dependent variability. Unlike CLC, which involves multiple accessory cones and lateral compaction, SC provides a more reproducible approach in in vitro models, allowing for more standardized comparisons across groups.

Retreatment Procedure

During retreatment, each canal was irrigated with a total of 10 mL of distilled water using Endo-Eze Tips (Ultradent Products Inc., South Jordan, UT, USA) attached to a 30-gauge side-vented needle. Irrigation was performed after each file use and also after completing the entire instrumentation sequence. For standardization, all retreatment procedures were performed using a single file system: The Perfect Super System Retreat ONE file. The file was operated at 500-600 rpm in the coronal third, 400 rpm in the middle third, and 250 rpm in the apical third, with a constant torque of 2.5 Ncm. Retreatment in each canal was completed using only this file, and the same protocol was consistently applied to all samples. The endpoint for retreatment was defined as the absence of visible filling material on the canal walls and on the instruments, confirmed by visual inspection under ×10 magnification using a stereomicroscope (Zeiss Stemi 508, Carl Zeiss, Germany).

Blinding Statement

To minimize bias, the operator performing the retreatment procedures was blinded to the group allocation. The retreatment files were presented in a randomized manner, and no identifying marks were present on the samples. However, the individual recording the retreatment time was not blinded to the group assignments.

Weight Measurement

The weight of each TAB was measured before and after the procedures using a precision balance (XB 220A; Kunz Precisa, Switzerland), and the differences were recorded in grams. The percentage of material loss was calculated using the following formula:

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

Time Measurement

The retreatment time was measured by an independent observer using a digital stopwatch (Neval Digital Stopwatch, Istanbul, Türkiye), considering only the active shaping time of the file within the canal. The durations of irrigation, patency checks, and drying procedures were excluded from the measurement.

Surface Area Analysis

High-resolution images (2560 × 1920 pixels, 300 dpi)

were captured and exported in TIF format using a stereomicroscope (Zeiss Stemi 508) at ×10 magnification, no staining was applied. The same settings were used for all pre- and post-retreatment images. No image enhancement or labeling was applied. The "initial area" referred to the portion of the canal surface covered by filling material prior to retreatment. The "post-RT area" represented the remaining filled surface after retreatment. The surface areas (mm^2) were calculated using ImageJ software (National Institutes of Health, Bethesda, MD, USA). Each image was binarized using a thresholding function in ImageJ, and manual segmentation was performed by outlining the filled areas. Measurements were taken by a single calibrated examiner blinded to group allocation. The filled area before and after retreatment was calculated in pixels, and the percentage of reduction was determined. The difference in area was evaluated as a percentage using the following formula:

Area Reduction (%)=(Initial Area – Post-RT Area) / Initial Area × 100

Statistical Analysis

Data was analyzed using SPSS version 27.0 (IBM Co., Armonk, NY, USA). The normality of distribution was assessed using the Shapiro-Wilk test, and since the data were not normally distributed, the Kruskal-Wallis test was applied. Although standardized acrylic blocks and a single operator were used, normal distribution was not achieved. This may be due to subtle procedural differences such as variations in gutta-percha condensation, material adaptation to canal walls, or manual segmentation in ImageJ, all of which can introduce micro-level variability despite standardization. For variables showing significant differences, Bonferroni-adjusted post hoc analyses and Mann-Whitney U tests were conducted for pairwise group comparisons. Spearman's rho correlation analysis was used to evaluate the relationships between variables. A p-value of <0.05 was considered statistically significant. None of the outcome variables passed the Shapiro–Wilk normality test (P<0.05). Although data transformation techniques (logarithmic and square root) were considered, they did not sufficiently normalize the distribution. Therefore, non-parametric tests (Kruskal–Wallis and Mann–Whitney U) were chosen instead of two-way ANOVA to ensure valid statistical interpretation without violating underlying assumptions.

The selection of the shaping and obturation systems was based on their distinct design philosophies and widespread clinical relevance, as previously described (10). These combinations allowed for a comparative evaluation of commonly used strategies and their potential impact on retreatment outcomes.

Results

In this study, a total of 80 TABs were used, each shaped with one of 4 different file systems and obturated using 2 distinct techniques. Three primary variables were evaluated: Weight difference of the removed filling, retreatment duration, and reduction in surface area based on gutta-percha area reference, calculated via ImageJ. Eight experimental groups were established (n=10); VR/SC, VR/CWC, PTN/SC, PTN/CWC, PTU/SC, PTU/CWC, XPS/SC, and XPS/CWC.

The initial analysis of the removed filling weight revealed a statistically significant difference among the groups (Kruskal-Wallis H=33.969; df=7; P<0.001). Post hoc comparisons showed that both XPS/SC and PTN/SC groups exhibited significantly greater weight difference compared to PTU/CWC and XPS/CWC groups (p_adj<0.05), with the XPS/SC group showing the highest mean value (3.5±0.3).

Retreatment time exhibited statistically significant differences among the groups, as confirmed by the Kruskal–Wallis test (H=51.150; df=7; P<0.001). The Bonferroni-adjusted Mann–Whitney U test revealed that the XPS/SC and PTN/SC groups required significantly more time than PTU/CWC and XPS/CWC groups (p_adj<0.05). Conversely, the shortest retreatment durations were observed in PTU/CWC (70±7) and XPS/CWC (80±6) groups.

Surface area reduction, calculated using ImageJ, also showed significant differences among the groups (Kruskal–Wallis H=34.654; df=7; P<0.001). After Bonferroni adjustment, only the comparison between the PTN/SC and XPS/CWC groups showed a statistically significant difference in surface area reduction (p_adj=0.0277) (Fig. 2). Although the XPS/SC group had the lowest mean

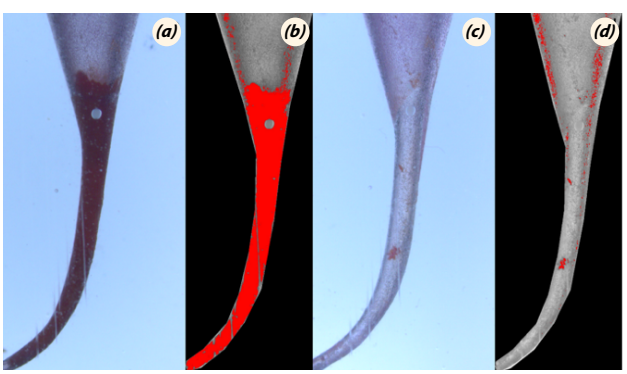


Fig. 2. Representative images of a sample from the PTN CWC group before and after retreatment. **(a)** Pre-retreatment stereomicroscopic image, **(b)** ImageJ segmentation of the pre-retreatment image (red overlay indicates gutta-percha-filled area). **(c)** Post-retreatment stereomicroscopic image of the same sample, **(d)** ImageJ segmentation of the post-retreatment image, with residual gutta-percha areas highlighted in red.

Table 1. Mean ± standard deviation values of the weight (mg), time (sec), and area reduction (%) differences among the groups.

Group	Weight	Time	Area Reduction
VR/SC	2.3 ± 0.4^{b}	120 ± 10^{B}	55 ± 5^{c}
VR/CWC	1.8 ± 0.5^{bc}	95±8C	$60\pm6b^{c}$
PTN/SC	3.1 ± 0.3^{a}	135 ± 12^{A}	50 ± 4^{c}
PTN/CWC	2.2 ± 0.6^{b}	100 ± 9^{C}	65 ± 5^{b}
PTU/SC	1.7 ± 0.5^{c}	90 ± 10^{C}	70 ± 6^{ab}
PTU/CWC	0.9 ± 0.4^{d}	70 ± 7^{D}	80 ± 7^{a}
XPS/SC	3.5 ± 0.3^{a}	140 ± 11^{A}	45 ± 3^{c}
XPS/CWC	1.1 ± 0.2^{d}	80 ± 6^{D}	75 ± 4^{a}

Different letters indicate statistically significant differences (P<0.05).

Table 2. Pairwise comparisons between groups showing statistically significant differences based on Bonferroni-adjusted Mann-Whitney U test results (P<0.05). Group names indicate the root canal shaping system and the type of obturation technique used.

Variable	Group 1	Group 2	p-value	Adjusted p-value
Weight difference	PTN/SC	PTU/CWC	0.00018	0.01534
Time	VR/CWC	PTN/SC	0.00018	0.01534
Time	VR/CWC	XPS/SC	0.00018	0.01534
Time	PTN/SC	PTN/CWC	0.00018	0.01534
Time	PTN/SC	PTU/CWC	0.00018	0.01534
Time	PTN/CWC	XPS/SC	0.00018	0.01534
Time	PTU/CWC	XPS/SC	0.00018	0.01534
Time	PTN/SC	XPS/CWC	0.00024	0.02056
Time	XPS/SC	XPS/CWC	0.00033	0.02756
Surface area reduction	PTN/SC	XPS/CWC	0.00033	0.02771

value, no statistically significant differences were detected between this group and others after correction. In general, groups obturated with the continuous wave compaction technique exhibited greater surface area reduction than those filled using the single-cone technique, with the highest reduction observed in the PTU/CWC group (80±7), followed by the XPS/CWC group (75±4). The descriptive statistics, including mean and standard deviation values for weight (mg), time (sec), and area reduction (%) across all groups, are summarized in Table 1. Post hoc comparisons indicated that groups sharing the same superscript letter in Table 1 were not significantly different from each other, whereas groups with different letters showed statistically significant differences ($p < 0.05$). Specifically, for weight difference, the XPS/SC and PTN/SC groups exhibited the highest mean values and were significantly different from PTU/CWC and XPS/CWC, which had the lowest values. For retreatment time, PTN/SC and XPS/SC groups had the longest durations, significantly differing from PTU/CWC and XPS/CWC groups, which had the shortest durations. Regarding surface area reduction, PTU/CWC showed the highest mean value, followed by XPS/CWC; both were significantly different from the lowest group, XPS/SC.

Spearman's correlation analysis demonstrated several key relationships among the study variables. A moderate, positive, and statistically significant correlation was observed between weight difference and retreatment time ($\rho=0.557$; $P<0.001$) and a significant negative correlation was identified between retreatment time and surface area reduction ($\rho=-0.370$; $p=0.001$). No significant correlation was found between weight difference and surface area reduction ($\rho=-0.061$; $p=0.593$). The results of the correlation analysis between the variables are shown in Table 2.

Discussion

This study aimed to investigate how different root canal shaping and obturation techniques used during the primary RCT influence the efficacy of subsequent nonsurgical endodontic retreatment, by assessing parameters such as filling removal, canal wall cleanliness, and procedural time. The findings revealed notable differences among the

groups regarding retreatment time, residual filling, and cleanliness of the canal walls. These outcomes underscore the critical role of both shaping kinematics and obturation techniques in influencing the efficiency and safety of retreatment procedures. Based on the statistically significant differences observed among the groups for all primary outcome measures, the null hypothesis of the study was rejected. A prominent outcome of the present study was the influence of the initial obturation technique on the effectiveness and efficiency of filling material removal.

Although various irrigants such as sodium hypochlorite, EDTA, and chlorhexidine are routinely employed in clinical endodontics for their antimicrobial and tissue-dissolving properties, distilled water was selected as the irrigant in the present study to eliminate the potential confounding effects of these chemically active agents on the tested artificial blocks. Previous studies (12,13) have demonstrated that these irrigants can alter the physical characteristics of synthetic canal models, potentially compromising the structural integrity of the simulated canals and resulting in inaccurate assessments of instrumentation efficacy. Therefore, the use of distilled water ensured a controlled environment and preserved the standardization required for valid comparisons among the different instrumentation systems.

Samples obturated with the continuous wave compaction technique generally demonstrated shorter retreatment durations compared to those filled using the single-cone technique. While certain SC groups, such as XPS/SC and PTN/SC, exhibited higher weight difference values, CWC groups achieved greater surface area reduction, with PTU/CWC and XPS/CWC showing the highest values. Samples obturated with the continuous wave compaction technique generally demonstrated shorter retreatment durations compared to those filled using the single-cone technique. While certain SC groups, such as XPS/SC and PTN/SC, exhibited higher weight difference values, CWC groups achieved greater surface area reduction, with PTU/CWC and XPS/CWC showing the highest values. These results support the conclusions drawn by Athkuri et al. (7), who found a greater percentage of residual material in canals initially obturated with thermoplasticized techniques. Olivieri et al. (8) similarly reported that warm vertical compaction techniques are more challenging to perform retreatment due to increased adaptation of filling into canal irregularities. The present findings are in agreement with a study by Rödig et al. (14) reporting no significant difference between carrier-based and warm vertical compaction techniques regarding residual filling and dentin removal.

Furthermore, among the shaping systems used prior to obturation, PTN and XPS showed superior performance in terms of residual material removal and canal wall cleanliness. The progressive taper of PTN and the adaptive design of the XPS allow for efficient shaping and debris removal, even in complex canal morphologies. These properties likely facilitated not only better primary canal preparation but also more accessible retreatment, as demonstrated in previous studies (15,16). In contrast, shaping with less flexible systems may result in irregular filling patterns and compromised retreatability.

The correlation analysis revealed two important trends: A moderate positive correlation between the amount of filling removed and retreatment time, and a negative correlation between retreatment time and canal wall cleanliness. In alignment with the findings of Çapar et al. (17) our study similarly demonstrated that root canals initially obturated with thermoplasticized techniques retain a significantly greater amount of residual material following retreatment procedures compared to SC obturated canals, emphasizing the impact of initial obturation modality on retreatment efficacy. These findings suggest that although longer instrumentation time may increase the volume of material removed. Most recent in vitro studies (18-21) have demonstrated that, regardless of the obturation technique used, complete removal of filling material is rarely achieved after retreatment, and some residual material remains in all specimens. However, some studies (19,22) reports inconsistent findings regarding the amount of residual filling material between the SC and CWC techniques. Some studies have indicated that canals obturated with the CWC method tend to be cleaner after retreatment, with significantly less remaining gutta-percha or sealer compared to the SC technique. It was reported (22) that canals obturated with the SC technique allowed faster achievement of working length and apical patency; however, a greater amount of residual filling material remained in these canals. In contrast, the same study found that retreatment of canals filled with the CWC technique required a slightly longer time, but resulted in less residual material. This difference has been attributed to the greater amount of sealer used in the SC technique, which may adhere more strongly to the dentinal walls and make complete removal more challenging. On the other hand, in a study (23) conducted on curved root canals using the same bioceramic sealer, no statistically significant difference was found between the SC and CWC techniques in terms of the amount of residual filling material after retreatment. In another study (24), it was observed that the CWC technique not only resulted in less residual filling material but also required a shorter retreatment time. In comparisons of apical debris extrusion during retreatment (25), it has

been reported that roots obturated with the warm vertical compaction technique exhibit significantly greater debris extrusion and require longer retreatment times compared to those filled with the cold lateral compaction technique. Despite these conflicting findings, it has been emphasized that when the type of sealer is kept constant, the choice of obturation technique is not a critical factor in retreatment success, as complete removal of filling material cannot be achieved in canals obturated with either technique—this is especially evident in cases with complex canal anatomy, where even extended mechanical action may fail to achieve optimal cleanliness (23).

Notably, the findings indicated no statistically significant association between the quantity of filling removed and the proportion of canal wall cleanliness. This observation highlights that extensive material removal does not inherently translate to effective debridement. Consistent with other studies (26,27) residual smear layers or sealer remnants may remain adherent to the canal walls even after substantial gutta-percha elimination.

The selection of standardized simulated canals contributed to enhanced experimental reproducibility; however, this approach inherently limited the anatomical diversity typically encountered in clinical settings. Although extracted human teeth offer more authentic root canal morphologies, their natural variability can hinder methodological standardization, making synthetic models a pragmatic alternative for controlled comparative studies (28-30).

To represent a broad range of modern endodontic instrumentation philosophies, four distinct file systems were intentionally selected for this study. PTN was included due to its extensive clinical validation and frequent use in practice. As a multi-file system utilizing M-Wire alloy and an off-centered design, PTN provides improved flexibility and shaping performance (31), making it suitable as a benchmark. PTU and VR were selected as newer generation multi-file systems that incorporate advanced heat-treated metallurgy and emphasize minimally invasive canal shaping (32,33).

These systems were evaluated specifically for their potential to enhance dentin preservation through such design attributes. In contrast, the XPS was chosen for its unique thermomechanical characteristics and single-file capability, which allowed for direct comparison with multi-file systems under standardized conditions (34).

In the present study, only gutta-percha was employed for obturating the root canals in the test TABs, and no root canal sealer was applied. This methodological choice represents a limitation of the study. The exclusion of sealer was primarily due to practical challenges, including difficulty in standardizing the sealer volume, achieving a uniform distribution within the canal, and controlling coronal or apical extrusion during the procedure. Similar experimental protocols without the use of sealer have been reported in prior studies (35–38). Nevertheless, we acknowledge the need for further investigations and recommend that future laboratory-based research be complemented with clinical studies to enhance the validity and applicability of the findings.

This study has several limitations. The in vitro setting does not fully represent clinical complexities. Only one retreatment system was used across all samples, which may not reflect variable retreatment approaches in practice. Additionally, the study did not assess post-operative pain, healing, or long-term outcomes. Despite these limitations, the results provide meaningful insights into how prior shaping and obturation techniques impact retreatment efficiency and can guide future research and clinical decision-making.

Conclusion

This in vitro study demonstrated that retreatment efficiency is influenced by both the initial canal shaping and obturation techniques. While some single-cone (SC) groups, such as XPS/SC, showed favorable outcomes in terms of material removal and surface cleanliness, they also exhibited longer retreatment durations compared to their thermoplasticized counterparts. Conversely, certain CWC groups demonstrated shorter retreatment times but lower efficiency in material removal. These findings highlight that neither obturation technique consistently outperformed the other across all parameters. Given the limitations of the standardized in vitro model, these results should be interpreted with caution. Further clinical investigations are warranted to validate the influence of primary root canal treatment protocols on retreatment efficacy under real-world conditions.

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Informed consent: No human or animal tissues or biological samples were used.

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