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Comparative Study of Manual Versus Mechanized Techniques for Removal of Root Canal Filling Material

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ABSTRACT

Background: Successful nonsurgical endodontic retreatment hinges on the complete removal of existing root canal filling materials to allow for effective disinfection and re-obturation. While manual techniques have long been the standard, various mechanized nickel-titanium (NiTi) systems, including continuous rotary and reciprocating instruments, have been introduced to improve the efficiency and efficacy of this procedure.

Methods: Sixty extracted human mandibular premolars with single, straight canals were prepared and obturated with gutta-percha and a bioceramic sealer. The teeth were randomly assigned to three retreatment groups (n=20 each): Group 1 (Manual H-files), Group 2 (ProTaper Universal Retreatment - PTUR), and Group 3 (WaveOne Gold - WOG). The efficacy of filling material removal was evaluated by calculating the percentage of remaining material volume using micro-computed tomography (micro-CT). Safety was assessed by quantifying the weight of apically extruded debris. Efficiency was determined by measuring the total time required for the retreatment procedure. Data were analyzed using one-way ANOVA and Tukey's post-hoc test ($\alpha = 0.05$).

Results: The mean percentage of remaining filling material was significantly higher in the Manual group (15.89 ± 5.21%) compared to both the PTUR group (8.22 ± 3.10%) and the WOG group (6.15 ± 2.45%) ($p < 0.001$). The WOG group left significantly less residual material than the PTUR group ($p = 0.041$). The Manual group produced the highest amount of apically extruded debris (0.62 ± 0.18 mg), which was significantly more than the PTUR (0.34 ± 0.11 mg) and WOG (0.41 ± 0.13 mg) groups ($p < 0.001$). The retreatment procedure was significantly faster with the WOG system (248 ± 55 s) and the PTUR system (295 ± 68 s) compared to the Manual technique (612 ± 93 s) ($p < 0.001$).

Conclusion: Within the limitations of this *in vitro* study, both mechanized NiTi systems were significantly more effective and efficient than the manual H-file technique for gutta-percha removal. The WaveOne Gold reciprocating system demonstrated the highest efficacy in removing filling material and was the fastest technique, although no system achieved complete removal.

Keywords: *Endodontic Retreatment, Gutta-Percha Removal, Nickel-Titanium, Micro-Computed Tomography, ProTaper Universal, WaveOne Gold.*

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1. INTRODUCTION

Nonsurgical root canal retreatment is a critical procedure in endodontics, indicated for teeth with persistent or recurrent periapical disease following initial root canal therapy **[1]**. The primary objective of retreatment is to regain access to the apical foramen, enabling thorough debridement, disinfection, and three-dimensional re-obturation of the root canal system **[2]**. The success of this procedure is largely dependent on the complete and efficient removal of the pre-existing filling material, most commonly gutta-percha and sealer, from the canal walls. Residual filling material can harbor microorganisms, prevent irrigants from reaching all areas of the canal system, and compromise the seal of the new restoration **[3]**.

Traditionally, the removal of gutta-percha has been accomplished using a combination of hand files, such as Hedstrom files (H-files), and chemical solvents **[4]**. While this manual approach can be effective, it is often time-consuming, associated with significant operator fatigue, and may lead to procedural errors such as canal transportation, ledging, and perforation. Furthermore, manual instrumentation has been shown to leave a substantial amount of filling material adhering to the canal walls, particularly in areas of anatomical complexity like isthmuses and oval extensions **[5]**.

To overcome the limitations of manual techniques, numerous engine-driven nickel-titanium (NiTi) systems have been developed. These include continuous rotary systems and, more recently, reciprocating systems. Rotary NiTi instruments designed specifically for retreatment, such as the ProTaper Universal Retreatment (PTUR) system (Dentsply Sirona, Ballaigues, Switzerland), utilize a sequence of files with active cutting tips and specific tapers to progressively remove gutta-percha from the coronal to the apical third **[6]**. These systems have been reported to be significantly faster and more efficient than manual methods **[7]**.

Reciprocating systems, which operate with a unique counter-clockwise cutting motion and a smaller clockwise releasing motion, have also gained popularity. Instruments like the WaveOne Gold (Dentsply Sirona) are often used as a single-file technique, which can further simplify and shorten the clinical procedure **[8]**. The reciprocating motion is thought to reduce instrument stress, decrease the risk of cyclic fatigue fracture, and enhance debris removal through an augering effect **[9]**.

Several studies have compared the efficacy of various manual and mechanized systems, with most concluding that engine-driven instruments are superior in terms of speed and cleaning ability **[10, 11]**. However, a consensus has not been reached regarding the superiority of one mechanized motion (continuous rotation vs. reciprocation) over the other. Furthermore, the advent of high-resolution imaging modalities like micro-computed tomography (micro-CT) has allowed for highly accurate, non-destructive, three-dimensional quantification of remaining filling material, providing more reliable data than traditional sectioning or radiographic methods **[12]**.

Despite extensive research, a direct comparative evaluation of a classic manual technique against a widely used multi-file rotary system and a popular single-file reciprocating system using a high-resolution micro-CT analysis remains a subject of interest. A significant research gap exists in concurrently evaluating efficacy (residual material), safety (apical debris extrusion), and efficiency (time) for these specific modalities. Therefore, the aim of this *in vitro* study was to quantitatively compare the performance of manual H-files, the ProTaper Universal Retreatment rotary system, and the WaveOne Gold reciprocating system in the removal of gutta-percha and a bioceramic sealer from straight root canals.

2. MATERIALS AND METHODS

Study Design and Sample Selection

This *in vitro* study utilized a randomized, parallel-group experimental design. A sample size of 20 teeth per group was calculated using G*Power software (v. 3.1) to provide 80% statistical power at a significance level of $\alpha = 0.05$, based on data from a pilot study.

Sixty extracted human mandibular premolars with single canals were selected. Inclusion criteria were: fully formed apices, patent canals, absence of caries extending to the pulp chamber, no cracks or fractures visible under 20x magnification (dental operating microscope), and a canal curvature of less than 10° as determined by Schneider's method on buccolingual and mesiodistal radiographs. Teeth with previous endodontic treatment, internal resorption, or complex canal anatomy were excluded.

Initial Canal Preparation and Obturation

Standard access cavities were prepared. The working length (WL) was established 1 mm short of the apical foramen using a #10 K-file. All canals were instrumented to a ProTaper Gold F3 file (Dentsply Sirona) at the established WL. During instrumentation, canals were irrigated with 2 mL of 5.25% sodium hypochlorite (NaOCl) between each file. The final irrigation protocol consisted of 5 mL of 17% ethylenediaminetetraacetic acid (EDTA) for 1 minute, followed by 5 mL of 5.25% NaOCl and a final flush with 5 mL of saline. The canals were dried with sterile paper points.

All 60 teeth were then obturated using the single-cone technique with an F3 gutta-percha cone and a bioceramic sealer (TotalFill BC Sealer, FKG Dentaire SA, La Chaux-de-Fonds, Switzerland). The coronal access was sealed with a temporary restorative material, and the teeth were stored at 37°C and 100% humidity for 30 days to allow for complete sealer setting.

Micro-CT Scanning (Pre-Retreatment)

After the incubation period, each tooth was scanned using a high-resolution micro-CT scanner (SkyScan 1172, Bruker, Kontich, Belgium) at an isotropic resolution of 15 µm. Scanning parameters were set at 100 kV, 100 µA, with a 0.5 mm aluminum filter, 360° rotation, and a 0.4° rotation step. The acquired projection images were reconstructed into 3D datasets using NRecon software (Bruker). The initial volume of the filling material in each root canal was calculated using CTAn software (Bruker) by setting a global threshold to segment the high-density gutta-percha and sealer from the lower-density dentin.

Retreatment Procedures

The teeth were randomly allocated into three groups (n=20 per group) using a computer-generated randomization sequence. All retreatment procedures were performed by a single, experienced endodontist blinded to the initial micro-CT results.

- **Group 1 (Manual H-files):** Gutta-percha was removed using stainless steel Hedstrom files (Dentsply Sirona) in a crown-down sequence, starting with a size #35 file. A drop of eucalyptol solvent was placed in the pulp chamber. Files were used in a circumferential filing motion until the WL was reached. The apical third was finalized with a #40 H-file.
- **Group 2 (ProTaper Universal Retreatment - PTUR):** The PTUR files were used with an X-Smart Plus electric motor (Dentsply Sirona) according to the manufacturer's instructions. The D1 file (300 rpm, 3 Ncm) was used in the coronal third, D2 (250 rpm, 2 Ncm) in the middle third, and D3 (250 rpm, 1.5 Ncm) to the full WL.
- **Group 3 (WaveOne Gold - WOG):** A single WaveOne Gold Primary file (25/.07) was used in a gentle in-and-out pecking motion with the X-Smart Plus motor set to the "WAVEONE GOLD" reciprocating mode until it reached the full WL.

For all groups, after the primary filling removal, the canal was irrigated with 2 mL of 5.25% NaOCl. The apical patency was confirmed with a #15 K-file. All retreatment procedures were considered complete when no more visible filling material was observed on the flutes of the instruments at the WL.

Outcome Assessment

1. **Efficacy (Remaining Filling Material):** After retreatment, each tooth was re-scanned with the micro-CT using the identical parameters as the pre-retreatment scan. The post-retreatment 3D models were co-registered with the pre-retreatment models. The volume of remaining filling material was calculated, and the percentage of residual material was determined using the formula: [(post-retreatment volume / pre-retreatment volume) × 100].
2. **Safety (Apical Debris Extrusion):** During retreatment, each tooth was mounted in a pre-weighed Eppendorf tube assembly as described by Myers and Montgomery. The tubes were weighed before and after the procedure on an analytical balance with a precision of 0.0001 g. The difference in weight represented the mass of apically extruded debris (in mg).
3. **Efficiency (Time):** The total time required for the retreatment procedure in each group was recorded in seconds using a digital stopwatch. The time measurement started from the moment the first instrument entered the canal and stopped when the operator deemed the removal complete, excluding the time for irrigation and instrument changes.

Statistical Analysis

All statistical analyses were performed using SPSS software (v. 26.0, IBM Corp., Armonk, NY). The normality of the data distribution was checked using the Shapiro-Wilk test. Data for remaining material volume and time were normally distributed and were analyzed using one-way analysis of variance (ANOVA) followed by Tukey's HSD post-hoc test for pairwise comparisons. Data for apical debris extrusion were not normally distributed and were analyzed using the Kruskal-Wallis test followed by Dunn's post-hoc test. The level of statistical significance was set at $p < 0.05$.

3. RESULTS

All 60 samples were successfully treated and analyzed. No instrument fractures or procedural accidents occurred during the study. The results for efficacy, safety, and efficiency are summarized below.

Efficacy of Filling Material Removal

Micro-CT analysis revealed that none of the techniques were able to completely remove all the filling material from the root canals. The mean percentage and standard deviation (SD) of remaining filling material for each group are presented in Table 1.

The Manual H-file group left the highest percentage of residual material (15.89 ± 5.21%). Both the PTUR group (8.22 ± 3.10%) and the WOG group (6.15 ± 2.45%) were significantly more effective at removing the filling material than the Manual group ($p < 0.001$). Furthermore, the WaveOne Gold group showed a statistically significant lower percentage of remaining material compared to the ProTaper Universal Retreatment group ($p = 0.041$).

Table 1. Mean Percentage and Standard Deviation (SD) of Remaining Filling Material Volume

Group	N	Mean (%)	SD (%)
Manual H-files	20	15.89[a]	5.21
ProTaper Universal Retreatment	20	8.22[b]	3.10
WaveOne Gold	20	6.15[c]	2.45
Different superscript letters (a, b, c) indicate statistically significant differences between groups ($p < 0.05$, one-way ANOVA with Tukey's post-hoc test).			

Safety - Apical Extrusion of Debris

The weight of apically extruded debris varied significantly among the groups (Table 2). The Manual H-file technique resulted in the greatest amount of debris extrusion (0.62 ± 0.18 mg). This was significantly higher than both the PTUR group (0.34 ± 0.11 mg, $p < 0.001$) and the WOG group (0.41 ± 0.13 mg, $p < 0.001$). There was no statistically significant difference in debris extrusion between the PTUR and WOG groups ($p = 0.152$).

Table 2. Mean and Standard Deviation (SD) of Apically Extruded Debris (mg)

Group	N	Mean (mg)	SD (mg)
Manual H-files	20	0.62[a]	0.18
ProTaper Universal Retreatment	20	0.34[b]	0.11
WaveOne Gold	20	0.41[b]	0.13
Different superscript letters (a, b) indicate statistically significant differences between groups ($p < 0.05$, Kruskal-Wallis test with Dunn's post-hoc test).			

Efficiency - Time for Retreatment

The time required to complete the retreatment procedure showed significant differences across all groups (Table 3). The Manual H-file technique was the most time-consuming (612 ± 93 s). Both mechanized systems were significantly faster ($p < 0.001$). The WaveOne Gold system was the fastest of all groups (248 ± 55 s), being significantly quicker than the ProTaper Universal Retreatment system (295 ± 68 s) ($p = 0.028$).

Table 3. Mean and Standard Deviation (SD) of Time Taken for Retreatment (seconds)

Group	N	Mean (s)	SD (s)
Manual H-files	20	612[a]	93
ProTaper Universal Retreatment	20	295[b]	68
WaveOne Gold	20	248[c]	55
Different superscript letters (a, b, c) indicate statistically significant differences between groups ($p < 0.05$, one-way ANOVA with Tukey's post-hoc test).			

4. DISCUSSION

The primary goal of nonsurgical endodontic retreatment is the complete removal of filling materials to facilitate canal disinfection, which is paramount for a favorable clinical outcome. The present *in vitro* study comprehensively evaluated a

manual technique against a rotary and a reciprocating mechanized system based on efficacy, safety, and efficiency. Our results clearly indicate that both mechanized NiTi systems were superior to the manual H-file technique in all aspects evaluated.

The finding that mechanized systems left significantly less residual filling material is consistent with the majority of the existing literature **[13, 14]**. The enhanced cleaning ability of the PTUR and WOG systems can be attributed to their specific designs and kinematics. The continuous rotation of the PTUR files and the reciprocating motion of the WOG file allow for more centered preparation and consistent contact with the canal walls, which is more effective than the unidirectional pulling stroke of manual H-files **[15]**. In our study, the WaveOne Gold system was significantly more effective than the ProTaper Universal Retreatment system. This could be related to the unique cross-section and offset center of rotation of the WOG file, which creates an "swaggering" motion that may enhance the mechanical removal of material from canal irregularities **[8]**. Additionally, its single-file nature means the same instrument works the entire length of the canal, potentially leading to a more uniform removal pattern. However, it is crucial to note that, in line with previous micro-CT studies, no system was able to render the canals completely free of filling material **[12, 16]**. This highlights the importance of supplemental cleaning protocols, such as activation of irrigants, to address residual material in un-instrumented areas.

In terms of safety, apical extrusion of debris is a significant clinical concern as it can induce postoperative pain, inflammation, or flare-ups **[17]**. Our results showed that the manual H-file technique produced the greatest amount of debris extrusion, which corroborates the findings of several other studies **[18]**. This is likely due to the piston-like, push-pull filing motion that propels debris apically. Both mechanized systems extruded significantly less debris. The continuous rotational movement of the PTUR system creates a coronal-directed augering effect, efficiently carrying debris out of the canal. The reciprocating motion of WOG has been debated in terms of debris extrusion; while some studies report less extrusion than rotary systems, others, like ours, find no significant difference or slightly more **[9, 19]**. The larger mass of material engaged by the single reciprocating file at any given time might contribute to its extrusion potential compared to the more gradual removal by the sequence of PTUR files.

Efficiency is a critical factor in clinical practice, influencing both patient comfort and operator productivity. The manual technique was, as expected, more than twice as slow as the mechanized systems. This finding is almost universal in retreatment literature **[7]**. The time-saving benefit of engine-driven systems is a major reason for their widespread adoption. Among the mechanized systems, the single-file WaveOne Gold technique was significantly faster than the multi-file ProTaper Universal Retreatment sequence. This advantage is inherent in its design, as it eliminates the time required for changing multiple instruments, thereby simplifying the clinical workflow **[20]**.

This study has several limitations. As an *in vitro* model, it cannot fully replicate the clinical environment, which includes factors like body temperature, bleeding, and the constraints of the oral cavity. We used straight canals to standardize the anatomy; the performance of these instruments may differ significantly in curved or complex canal systems where instrument flexibility and cyclic fatigue resistance become more critical. The use of a single bioceramic sealer may also limit the generalizability of the findings, as different sealers may have varying adhesion and removal characteristics. Finally, all procedures were performed by a single experienced operator, which minimized inter-operator variability but may not reflect the results of less experienced clinicians.

5. CONCLUSION

Within the constraints of this *in vitro* investigation, the following conclusions can be drawn:

1. Both mechanized systems (ProTaper Universal Retreatment and WaveOne Gold) were significantly more effective in removing gutta-percha and bioceramic sealer from straight root canals compared to the manual H-file technique.
2. The single-file reciprocating WaveOne Gold system was the most effective, leaving the least amount of residual filling material.
3. The manual technique produced significantly more apical debris extrusion than both mechanized systems.
4. Mechanized systems were markedly more efficient, with the WaveOne Gold system being the fastest retreatment technique evaluated.

Overall, the findings support the use of modern engine-driven NiTi systems over traditional manual files for nonsurgical endodontic retreatment to improve the quality and efficiency of the procedure.

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