RESEARCH PAPER

Comparative Evaluation of Manual, Ultrasonic, and Laser-Activated Irrigation on the Retreatability of Silicone-Based Endodontic Sealer: A CBCT-Based Volumetric Analysis

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ABSTRACT

The success of endodontic retreatment depends on the thorough removal of obturating materials from the root canal system. Silicone-based sealers exhibit strong adhesion and deep dentinal tubule penetration, making retreatment challenging. Energy-enhanced irrigation techniques, including ultrasonic and LASER activation, have been proposed as adjuncts to conventional mechanical methods. Aims: To evaluate and compare the retreatability of silicone-based sealer using manual instrumentation, ultrasonic-activated irrigation, and diode LASER-activated irrigation, with volumetric assessment through CBCT. Methods and Materials: Thirty extracted single-rooted mandibular premolars with straight canals were prepared using standardized protocols and obturated with GuttaFlow bioseal by warm vertical compaction. After 14 days of incubation, samples were randomly divided into three groups (n = 10): Group 1 – manual retreatment with Hedström files; Group 2 – ultrasonic-activated irrigation (25–30 kHz); Group 3 – diode LASER-activated irrigation (810–980 nm). Pre- and post-retreatment CBCT scans were analysed using three-dimensional reconstruction software to determine the percentage of residual filling material. Statistical analysis used: One-way ANOVA and Tukey's HSD test ($\alpha = 0.05$). Results: LASER-activated irrigation showed the highest removal efficacy (86.86 ± 2.94%), followed by ultrasonic activation (75.38 ± 3.65%) and manual instrumentation (52.48 ± 4.12%). Significant intergroup differences were observed ($p < 0.001$). LASER activation was superior to both ultrasonic and manual methods, and ultrasonic activation was significantly better than manual retreatment. Conclusions: Diode LASER-activated irrigation was the most effective technique for removing silicone-based sealer, followed by ultrasonic activation, while manual instrumentation showed the lowest efficacy. Energy-activated irrigation significantly improves retreatment outcomes.

Keywords: Endodontic retreatment; Silicone-based sealer; GuttaFlow bioseal; LASER-activated irrigation; Passive ultrasonic irrigation; Cone-beam computed tomography; Volumetric analysis; Filling material removal

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Key Message: Diode LASER–activated irrigation significantly enhances the removal of silicone-based endodontic sealers compared with ultrasonic activation and conventional manual retreatment, as confirmed by CBCT-based volumetric analysis. Incorporating energy-activated irrigation techniques may substantially improve the efficiency and predictability of endodontic retreatment procedures.

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Conflict of interest: None

Introduction:

Endodontic retreatment is a critical therapeutic intervention necessitated by the failure of primary root canal therapy, most commonly attributed to persistent infection, incomplete biomechanical preparation, undetected canal anatomy, or coronal leakage[1]. The fundamental objective is complete elimination of existing obturating materials to allow thorough re-cleaning, disinfection, and re-obturation of the root canal system[2]. However, achieving comprehensive sealer removal remains a significant clinical challenge, particularly with contemporary adhesive formulations engineered to enhance canal wall bonding and tubular penetration.

Silicone-based sealers such as GuttaFlow bioseal incorporate gutta-percha particles within a polydimethylsiloxane matrix, yielding favorable biocompatibility, dimensional stability, and sustained antimicrobial activity[3]. However, their pronounced penetration into dentinal tubules and strong adhesion to radicular dentin simultaneously create formidable obstacles during retreatment, frequently resulting in residual sealer that impedes irrigant penetration and may compromise long-term prognosis[4–5]. Traditional mechanical instrumentation alone is often insufficient to address sealer retained within canal irregularities, isthmuses, and lateral ramifications[6].

To augment filling material removal, energy-activated irrigation modalities have been developed. Passive ultrasonic irrigation (PUI) generates acoustic microstreaming and cavitation phenomena that mechanically dislodge debris and sealer remnants from canal walls[7–8]. LASER-activated irrigation (LAI) using near-infrared diode LASERs additionally induces photoacoustic and photothermal effects, softening the silicone matrix while generating enhanced irrigant turbulence[9–10]. Cone-beam computed tomography (CBCT) provides high-resolution three-dimensional volumetric quantification of residual filling material, offering superior accuracy over conventional two-dimensional radiography and enabling non-destructive pre- and post-treatment comparisons on identical specimens[11–12].

Despite the growing clinical adoption of silicone-based sealers and energy-activated systems, direct comparative evidence evaluating manual instrumentation, PUI, and diode LAI specifically for GuttaFlow bioseal retreatment using CBCT volumetric assessment remains scarce. This study aimed to compare the retreatability of GuttaFlow bioseal across these three methodologies, hypothesizing that statistically significant differences in sealer removal efficiency would exist among the groups.

Subjects and Methods:

This in-vitro randomized comparative study was conducted with institutional approval for the use of extracted human teeth. Thirty freshly extracted single-rooted mandibular premolars were selected based on the following criteria: mature and completely formed apices, Vertucci Type I canal configuration confirmed radiographically, absence of cracks, resorption, calcifications or prior endodontic treatment. Teeth were cleansed of soft tissue and stored in 0.1% thymol solution until use. Coronal portions were sectioned perpendicular to the long axis to standardize root length at 15 mm; working length was established at 14 mm using a size 10 K-file.

Canal Instrumentation and Obturation were performed using a crown-down technique with ProTaper Universal NiTi Rotary files (Dentsply Maillefer) progressing to size F3 (300 rpm, 2.0 Ncm torque), with 2.5% NaOCl irrigation (15 mL total) between each file change. Final irrigation consisted of 17% EDTA (5 mL, 1 minute) followed by sterile distilled water. All specimens were obturated with GuttaFlow bioseal (Coltene/Whaledent AG, Altstatten, Switzerland) using warm vertical compaction to ensure three-dimensional adaptation to canal walls. Access cavities were sealed with Cavit G (3M ESPE) and specimens were incubated at 37°C and 100% relative humidity for 14 days to allow complete sealer setting.

Following the setting period, specimens were randomly allocated using computer-generated sequences into three groups (n=10 each). Group 1 (Manual Retreatment) used Hedström files (sizes 40–25) in a circumferential filing motion supplemented with conventional needle irrigation (2.5% NaOCl, 10 mL total via 27-gauge side-vented needle). Group 2 (Ultrasonic Activation) received the same initial mechanical debridement, followed by passive ultrasonic irrigation using a P5 Newtron unit (Satelec Acteon) with an Irrisafe stainless steel tip (size 30 kHz) positioned 1 mm short of working length; three 30-second activation cycles were performed with freshly replenished 2.5% NaOCl (3 mL per cycle). Group 3 (LASER Activation) received equivalent mechanical debridement followed by 940 nm diode LASER-activated irrigation (Sirolase Blue Dentsply Sirona; 200 µm optical fiber, 1.5 W, continuous wave) in three 20-second activation cycles with 2.5% NaOCl (3 mL per cycle), using sweeping helical motion with the fiber tip 2

mm short of working length. All groups received a standardized final irrigation of 5 mL 17% EDTA followed by 5 mL sterile saline.

Pre- and post-retreatment CBCT scans were acquired using a standardized protocol (CS 9300, Carestream Dental; 90 kVp, 4 mA, 0.125 mm voxel size, 5×5 cm field of view) . Volumetric quantification of filling material was performed by a single blinded calibrated examiner using semi-automated threshold-based segmentation (CS 3D Imaging Software). Percentage removal was calculated as [(Initial Volume − Residual Volume)/Initial Volume] × 100. Statistical tests applied for Data normality is Shapiro-Wilk test and variance homogeneity were confirmed by Levene's test, and statistical comparisons were performed using one-way ANOVA with Tukey's HSD post-hoc test (SPSS v25.0; $\alpha = 0.05$)

Results:

The mean initial obturation volumes were comparable across all three groups, indicating adequate baseline standardization prior to retreatment. The manual retreatment group showed an initial volume of 12.45 ± 1.22 mm³, while the ultrasonic and LASER activation groups recorded initial volumes of 12.67 ± 1.31 mm³ and 12.55 ± 1.18 mm³, respectively (Table 1).

Following retreatment procedures, differences were observed in the amount of remaining sealer among the groups. The manual retreatment group exhibited the highest residual volume (5.92 ± 0.88 mm³), corresponding to the lowest percentage of sealer removal (52.48 ± 4.12%). In comparison, the ultrasonic activation group demonstrated improved cleaning efficiency, with a reduced residual volume of 3.12 ± 0.74 mm³ and a mean percentage removal of 75.38 ± 3.65%. Among all groups, LASER activation achieved the greatest sealer removal efficacy. This group showed the lowest remaining sealer volume (1.65 ± 0.51 mm³) and the highest mean percentage removal (86.86 ± 2.94%) (Table 1).

Post-hoc pairwise comparison using Tukey's Honest Significant Difference (HSD) test demonstrated statistically significant differences among all groups in terms of percentage removal of the sealer. LASER activation showed significantly greater removal efficiency compared with ultrasonic activation, with a mean difference of 11.48% (standard error: 1.12; $p = 0.032$), indicating a statistically significant improvement (Table 2).

When compared with manual retreatment, LASER activation demonstrated a markedly higher removal efficiency, with a mean difference of 34.38% (standard error: 1.54; $p < 0.001$), representing a highly significant difference. Similarly, ultrasonic activation also showed significantly better performance than manual instrumentation, with a mean difference of 22.90% (standard error: 1.43; $p < 0.001$), which was also highly significant (Table 2).

The intraclass correlation coefficient for intra-examiner reliability was 0.96, indicating excellent measurement reproducibility. Shapiro-Wilk testing confirmed normal data distribution for all groups ($p > 0.05$), and Levene's test demonstrated homogeneity of variance ($p = 0.312$), justifying the use of parametric statistical tests.

Table 1: Table showing Descriptive Statistics and One-Way ANOVA for Retreat ability based on CBCT Volumetric Analysis

Group	Number of samples	Initial Volume (mm³) Mean ± SD	Remaining Volume (mm³) Mean ± SD	Percentage Removal Mean ± SD	F-value	p-value
Manual Retreatment	10	12.45 ± 1.22	5.92 ± 0.88	52.48 ± 4.12	68.42	**< 0.001***
Ultrasonic Activation	10	12.67 ± 1.31	3.12 ± 0.74	75.38 ± 3.65		
Laser Activation	10	12.55 ± 1.18	1.65 ± 0.51	86.86 ± 2.94		

Table 2: Table showing comparative analysis between the three groups based on Post-Hoc Tukey HSD.

Group Comparison	Mean Difference (% Removal)	Standard Error	p-value	Significance
Laser vs Ultrasonic	11.48	1.12	**0.032***	Significant
Laser vs Manual	34.38	1.54	**< 0.001***	Highly Significant

Ultrasonic vs Manual	22.90	1.43	**< 0.001***	Highly Significant

Discussion:

The present investigation demonstrates that irrigation activation technique significantly influences the retreatability of GuttaFlow Bioseal, with LASER activation achieving the highest sealer removal efficiency, followed by ultrasonic activation, while conventional manual instrumentation proved least effective. These findings underscore the inadequacy of mechanical debridement alone when managing modern adhesive silicone-based sealers and highlight the clinical value of energy-enhanced irrigation adjuncts.

The superior performance of LASER activation is attributable to its unique combination of photomechanical and photothermal mechanisms. Diode LASERS operating in the near-infrared spectrum generate photoacoustic phenomena characterized by rapid formation and collapse of vapor bubbles within the irrigant, producing shock waves and intense fluid agitation that mechanically disrupt the sealer-dentin interface[9,17]. Simultaneously, photothermal energy absorption facilitates softening of the silicone matrix, reducing its adhesive resistance to removal[10]. These synergistic mechanisms enable irrigant penetration into dentinal tubules and anatomical complexities inaccessible to mechanical instruments. The present findings are consistent with Obeid et al.[10,14], who reported significantly improved GuttaFlow bioseal retrieval with diode LASER activation, and with Almohareb et al.[13], who demonstrated LASER superiority over PUI for bioceramic sealers across a comparable experimental design.

Ultrasonic activation substantially outperformed manual instrumentation, corroborating its well-established role as an effective retreatment adjunct. PUI generates acoustic microstreaming and transient cavitation that create oscillating fluid currents capable of dislodging sealer remnants from canal walls and irregularities beyond the reach of instruments[7,18]. Unlike LASER activation, ultrasonic energy produces no meaningful thermal effects on the obturating material, relying entirely on mechanical agitation — a distinction that likely accounts for the intermediate efficacy observed. The 75.38% removal achieved by PUI in this study aligns with the findings of Keleş et al.[8,19], who reported significant improvements in sealer removal with ultrasonic irrigation compared to conventional protocols.

Manual instrumentation achieved only 52.48% sealer removal, reflecting the inherent limitations of instruments that act solely through direct mechanical contact. Hand files cannot effectively access sealer retained within dentinal tubules, lateral canals, isthmuses, or apical irregularities, and conventional needle irrigation lacks the activation energy necessary to disrupt the strong adhesive bond characteristic of silicone-based sealers[6]. These observations are consistent with Rossi-Fedele and Ahmed[6] and Saad et al.[20], who documented that mechanical debridement alone consistently yields significant residual material, particularly with modern adhesive sealer formulations.

The use of CBCT for volumetric quantification represents a significant methodological strength, enabling non-destructive pre- and post-retreatment comparisons on identical specimens, thereby eliminating inter-specimen variability and enhancing statistical precision[11,12]. Limitations include the in-vitro design, which cannot fully replicate clinical variables such as canal curvature, periapical inflammation, moisture dynamics, and operator variability. The exclusive use of straight single-rooted teeth limits generalizability to more complex anatomical configurations encountered clinically. Additionally, only one sealer formulation and one LASER system with fixed parameters were evaluated; different silicone-based formulations or LASER wavelengths (e.g., Er:YAG) may exhibit different removal characteristics.

The substantial differences in removal efficiency among groups carry direct clinical relevance. Clinicians retreating teeth obturated with silicone-based sealers should strongly consider supplementing mechanical instrumentation with energy-activated irrigation. LASER activation, when available, offers the greatest cleaning efficacy; PUI provides a highly accessible, cost-effective alternative with meaningful improvement over manual techniques alone. Importantly, even the most effective modality left 13.14% residual sealer, highlighting that complete material removal remains unachievable with current techniques and reinforcing the importance of thorough antimicrobial protocols in areas where remnants persist.

Conclusion:

Within the parameters and limitations of this in-vitro investigation, diode LASER-activated irrigation demonstrated the highest efficacy for GuttaFlow bioseal removal (86.86%), followed by passive ultrasonic

irrigation (75.38%), with conventional manual instrumentation showing significantly inferior performance (52.48%). All pairwise intergroup differences were statistically significant ($p \leq 0.032$). Energy-activated irrigation — particularly LASER activation, or PUI as a practical alternative — should be considered an essential adjunct to mechanical debridement during retreatment of teeth obturated with silicone-based sealers. CBCT-based volumetric analysis proved a reliable and reproducible methodology for quantifying retreatment efficacy in this context.

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