Original Research

Title: Retreatability of guttaflow bioseal in bulk or with main cone from root canals using ultrasonic, laser, and xp-endo finisher activated techniques

Running Title: Retreatability of guttaflow bioseal

Authors Esin Özlek [1*], Gizem Kadı [2], Hüseyin Gündüz [3], Yousef Saed [4]

Affiliations: [1] Department of Endodontics, Faculty of Dentistry, Van Yüzüncü Yıl University, Van, Turkey

[2] Department of Endodontics, Faculty of Dentistry, Altınbaş University, İstanbul, Turkey

[3] Department of Endodontics, Faculty of Dentistry, Bilecik Şeyh Edebali University, Bilecik, Turkey

[4] Faculty of Dentistry, Arab American University, Janīn, West Bank, Palestine

Received: 20.08.2024

Revised: 13.12.2024

Accepted: 25.03.2025

DOI: 10.26650/eor.20251536018

Authors' ORCID:

Esin Ozlek 0000-0003-1446-284X
Gizem Kadı 0000-0001-5577-7229
Hüseyin Gündüz 0000-0003-1580-3159
Yousef Saed 0000-0001-8361-4734

Corresponding author: Esin Özlek - esin_ozlek@hotmail.com

How to cite: Özlek E, Kadı G, Gündüz H, Saed Y. Retreatability of guttaflow bioseal in bulk or with main cone from root canals using ultrasonic, laser, and xp-endo finisher activated techniques. Eur Oral Res. Advance online publication.

UNDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record

Abstract

Purpose: The aim of this study was to investigate the efficacy of ultrasonic, laser, and XP-Endo Finisher activation techniques for the removal of GuttaFlow Bioseal from root canals.

Materials and Methods: In this study, 64 extracted mandibular premolar teeth were instrumented using ProTaper Next files up to size X3 and randomly divided into two groups (n = 32) based on the obturation method: Group 1 — GuttaFlow Bioseal with gutta-percha, and Group 2 — GuttaFlow Bioseal without gutta-percha. After root filling removal, the specimens were randomly allocated into one of four activation subgroups (n = 8): Subgroup A — Conventional Needle Irrigation; Subgroup B — Passive Ultrasonic Activation; Subgroup C — XP-Endo Finisher; and Subgroup D — Er, Cr: YSGG Laser. The teeth were then sectioned longitudinally, and photographic images were captured under a stereomicroscope. Residual filling materials in the coronal, middle, and apical thirds were measured using ImageJ software. Data were statistically analyzed with three-way ANOVA and Tukey's HSD test ($p < 0.05$).

Results: The lowest amount of residual filling material was observed in the Er, Cr: YSGG laser group, followed by the XP-Endo Finisher, passive ultrasonic activation, and conventional needle irrigation groups, respectively ($p < 0.001$). There was no statistically significant difference in retreatability between GuttaFlow Bioseal used with or without gutta-percha ($p = 0.754$).

Conclusion: This study demonstrates that different activation techniques significantly improve the removal of GuttaFlow Bioseal from root canals; however, none achieved complete removal. Among the tested methods, the Er, Cr: YSGG laser was the most effective, followed by the XP-Endo Finisher and passive ultrasonic activation. These results suggest that the Er, Cr: YSGG laser is a highly effective option for endodontic retreatment.

Keywords: *endodontics, root canal therapy, laser therapy, ultrasonics, root canal filling materials*

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record

Türkçe öz: *Guttaflow bioseal'in tek başına ya da ana kon ile kullanıldığı kök kanallarında dolgu materyalinin uzaklaştırılmasına ultrasonik, lazer ve xp-endo finisher aktivasyon yöntemlerinin etkisi. Bu çalışmanın amacı, GuttaFlow Bioseal'in kök kanallarından uzaklaştırılmasında ultrasonik, lazer ve XP-Endo Finisher aktivasyon tekniklerinin etkinliğini araştırmaktır. Bu çalışmada, 64 adet mandibular premolar diş ProTaper Next eğeleriyle X3'e kadar şekillendirilmiş ve dolgu yöntemine göre rastgele iki gruba ayrılmıştır (n=32): Grup 1, GuttaFlow Bioseal ile birlikte gutta-perka; Grup 2, gutta-perka olmadan yalnızca GuttaFlow Bioseal. Kök kanal dolguları uzaklaştırıldıktan sonra örnekler aktivasyon tekniklerine göre rastgele dört alt gruba ayrılmıştır (n=8): Alt grup A, Konvansiyonel İğne ile İrrigasyon; Alt grup B, Pasif Ultrasonik Aktivasyon; Alt grup C, XP-Endo Finisher; ve Alt grup D, Er,Cr:YSGG lazer. Dişler uzunlamasına kesilmiş ve stereomikroskop altında fotoğrafları çekilmiştir. Koronal, orta ve apikal üçlüde kalan dolgu materyali miktarı Image J yazılımı kullanılarak hesaplanmıştır. Veriler, üç yönlü ANOVA ve Tukey HSD testleriyle istatistiksel olarak analiz edilmiştir ($p<0.05$). En düşük dolgu kalıntısı Er,Cr:YSGG lazer grubunda, ardından sırasıyla XP-Endo Finisher, pasif ultrasonik aktivasyon ve konvansiyonel iğne gruplarında gözlemlenmiştir ($p<0.001$). GuttaFlow Bioseal'in gutta-perka ile veya yalnız kullanılması arasında istatistiksel olarak anlamlı bir fark bulunmamıştır ($p=0.754$). Bu çalışma, farklı aktivasyon tekniklerinin GuttaFlow Bioseal'in kök kanallarından uzaklaştırılmasını anlamlı düzeyde artırdığını göstermektedir; ancak hiçbir teknik tam anlamıyla dolgu materyalini uzaklaştıramamıştır. Test edilen yöntemler arasında en etkili olan Er,Cr:YSGG lazer olarak belirlenmiş; onu XP-Endo Finisher ve pasif ultrasonik aktivasyon takip etmiştir. Bu sonuçlar, Er,Cr:YSGG lazerin endodontik retreatment için oldukça etkili bir yöntem olduğunu göstermektedir.*

Anahtar kelimeler: *endodonti, kök kanal tedavisi, lazer, ultrasonik aktivasyon, kök kanal dolgu materyalleri*

Introduction

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record

UNEDITED PROOF

Endodontic treatment aims to achieve and maintain healthy conditions in the periapical tissues (1). However, due to various factors, approximately 15–22% of these treatments may fail. Causes of failure include inadequate canal cleaning, insufficient canal filling, and microleakage (2). Management options for failed root canal therapy include nonsurgical retreatment, surgical endodontic intervention such as apical surgery, and intentional tooth replantation. Compared to other options, nonsurgical root canal retreatment is generally preferred because it is less invasive and offers a higher likelihood of success (3).

Endodontic retreatment involves removing previously placed root canal filling materials up to the apical end, followed by mechanical re-instrumentation, disinfection, and re-obturation of the canals. Thorough removal of root canal filling residues is crucial for the success of retreatment procedures, as remaining materials may serve as reservoirs for microorganisms, reduce the efficacy of irrigants, hinder the adaptation of new filling materials, and ultimately compromise treatment outcomes (4).

Various techniques and instruments, including hand files, ultrasonic devices, reciprocating systems, and adaptive instruments, are used during root canal retreatment. Despite technological advancements, the complexity of root canal morphology and the mechanical limitations of manual instruments often prevent the complete removal of filling residues from hard-to-reach areas such as isthmuses or anatomically curved and oval canals (5). To address these challenges, supplementary techniques and advanced technologies have been developed alongside conventional methods. Devices such as passive ultrasonic irrigation (PUI), laser systems, and specially designed instruments like the XP-Endo Finisher (XP) play a key role in effectively removing residual filling materials from the complex root canal system, particularly in difficult-to-access regions (6).

PUI operates at a frequency of approximately 30 kHz, agitating the irrigant within the canal to create acoustic streaming and cavitation. This enhances canal disinfection and aids in

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record

removing the smear layer and debris, especially in hard-to-reach areas such as oval-shaped canals (7). To further improve cleaning efficiency in complex anatomies, rotary nickel-titanium (NiTi) systems have been developed. One notable example is the XP-Endo Finisher, which is made from a thermomechanically treated NiTi alloy. This alloy transforms from the martensitic to the austenitic phase at body temperature, enabling eccentric rotational movement within the canal. This unique movement allows the instrument to adapt to irregular canal shapes and facilitates more effective removal of filling materials. The XP's 0.25 mm core diameter and lack of taper allow for optimal flexibility and cleaning within the canal (6,8).

The Er,Cr:YSGG laser (erbium, chromium-doped yttrium, scandium, gallium, and garnet), operating at a wavelength of 2780 nm, demonstrates strong absorption in hydroxyapatite and water. This enables efficient cleaning of canal walls while minimizing thermal damage to surrounding tissues compared to other laser systems (9).

GuttaFlow Bioseal, a silicone-based root canal sealer containing calcium silicate particles (Coltene, Whaledent, Langenau, Switzerland), is characterized by high water absorption, low solubility, and low porosity. It has become increasingly popular in endodontic practice due to its unique properties. GuttaFlow Bioseal offers distinct advantages, including promoting alkalization and hydroxyapatite formation within the canal through calcium ion release (10,11). However, studies have shown that GuttaFlow Bioseal cannot be completely removed from root canals once placed (12,13). Yet, one fundamental requirement of an ideal root canal sealer is that it should be fully and effectively removable if needed.

This research was conducted to evaluate how effectively GuttaFlow Bioseal can be removed when used alone or in combination with gutta-percha, using rotary instrumentation combined with four different irrigant agitation protocols. The null hypotheses of this study were: there is no difference in the retreatability of GuttaFlow Bioseal used alone or with gutta-

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record

percha; and the irrigant activation techniques (XP-Endo Finisher, Er,Cr:YSGG laser, and PUI) have no effect on the removal of the root filling materials.

Materials and Methods

Ethical statement

The research protocol received approval from the Ethics Committee of Van Yüzüncü Yıl University (Approval No: 21/01/2022-16).

Sample size estimation

The sample size was determined using G*Power software (Heinrich Heine University, Düsseldorf, Germany), based on data reported by Machado *et al.* (14). Power analysis was performed using an effect size of f = 0.577, a significance level of 0.05, and a power of 90%, resulting in a minimum required sample size of 64 specimens.

Sample preparation

In this study, 64 extracted mandibular premolars (N = 64) with straight, single root canals were selected. The teeth had been extracted for orthodontic or periodontal reasons. The presence of a single canal was confirmed radiographically using mesiodistal and buccolingual projections. Only teeth with fully developed apices and no root curvature, cracks, fractures, caries, anomalies, or resorptive defects were included. After removal of any soft tissue remnants and surface calculus, all specimens were stored in a 0.5% thymol solution in distilled water until further use. The coronal portions of the teeth were sectioned using a slow-speed diamond saw under continuous water cooling to standardize the root length to 15 mm.

Working length was determined by inserting a size 15 K-file until its tip was visible at the apical foramen; 1 mm was then subtracted from this measurement. Root canals were prepared using ProTaper Next files (Dentsply Sirona, Konstanz, Germany) up to size X3, operated with an X-Smart Plus motor (Dentsply Maillefer, Ballaigues, Switzerland) at 300 rpm,

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record

employing the crown-down technique. During instrumentation, the canals were irrigated with 2 mL of 5.25% sodium hypochlorite (Microvem AF, Istanbul, Turkey) for one minute at each file change. After shaping, a final irrigation was performed with 5 mL of 17% EDTA (Imident™ Med., Konya, Turkey) for one minute to remove the smear layer, followed by 5 mL of 2.5% NaOCl. Finally, the canals were flushed with 5 mL of saline solution and dried thoroughly using sterile paper points.

All irrigation procedures were carried out with a 2 mL syringe and a 31G side-vented needle, keeping the needle tip 2 mm short of the working length to minimize the risk of apical extrusion. Based on the obturation method, the specimens were then randomly divided into two equal groups of 32 teeth each.

Study groups

In GuttaFlow Bioseal with Gutta-Percha group (Group 1) the single-cone technique was used to obturate the root canals with GuttaFlow Bioseal. The material was applied using the plastic applicator tip provided by the manufacturer. A master gutta-percha cone (size 30, .06 taper; Dentsply, Ballaigues, Switzerland) was fitted to the working length, ensuring adequate tug-back. In Group 2 (GuttaFlow Bioseal without Gutta-Percha) GuttaFlow Bioseal was delivered into the canal using a plastic applicator tip, which was gradually withdrawn from the apical portion toward the coronal opening to ensure uniform distribution throughout the canal. Caviton (GC, Tokyo, Japan) was used to seal the coronal openings of the canals. The quality of the obturation was verified radiographically in mesiodistal and buccolingual directions. Specimens with insufficient or non-homogeneous root fillings were replaced. After obturation, all specimens were stored in an incubator at 37 °C and 100% relative humidity for 14 days to ensure complete setting.

Retreatment procedure

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record

The root canal filling materials were removed using the ProTaper Universal Retreatment system (Dentsply Maillefer, Ballaigues, Switzerland) operated at 500 rpm. The D1, D2, and D3 files were used in sequence, without chemical solvents. Retreatment was considered complete when the working length was reached and the canal walls and instruments were free of visible gutta-percha or sealer. Between each step, canals were irrigated with 2 mL of 5.25% NaOCl. To maintain standardization and file performance, new instruments were used for every fifth specimen.

Final ırrigant activation techniques

Following retreatment, the canals were irrigated with 5 mL of 17% EDTA for one minute. The specimens were then randomly divided into four equal subgroups (n = 8) according to the final irrigant activation technique: Subgroup A (CNI): Irrigation was performed with 5.25% NaOCl delivered via syringe equipped with a closed-end 27-gauge needle. The needle was inserted 1 mm short of the working length and moved vertically (2–3 mm amplitude) at approximately 100 strokes per minute for one minute. This cycle was repeated until a total of 5 mL NaOCl had been used. Subgroup B (PUI): Canals were filled with 5.25% NaOCl, activated using a 21 mm IRR20 ultrasonic tip (Satelec Acteon Group, Merignac, France) attached to an irrigation device (VDW, Munich, Germany). The tip was positioned 1 mm short of the working length and moved up and down within a 2–4 mm range for 20 seconds. This was performed in three 20-second cycles (total: 1 minute), repeated until 5 mL of NaOCl had been delivered. Subgroup C (XP): After placing 5.25% NaOCl in the canal, the XP (FGK, Switzerland) was operated according to the manufacturer's instructions using an X-Smart Plus motor (Dentsply Maillefer, Ballaigues, Switzerland) set to 800 rpm and 1 N·cm torque. The instrument was placed 1 mm short of the working length and activated for 20 seconds with gentle longitudinal strokes (7–8 mm amplitude). This was performed in three 20-second cycles (total: 1 minute), repeated until a total of 5 mL NaOCl had been used. Subgroup D (Er,Cr:YSGG Laser): After

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record

canal preparation, 5.25% NaOCl was introduced and activated using an Er,Cr:YSGG laser system with an RFT2 tip (diameter: 275 µm; length: 21 mm), positioned 1 mm short of the working length. Laser activation was performed at 2 W output power, 20 Hz pulse frequency, and settings of 10% air and 10% water (energy density: 23.15 J/cm²). Irradiation was applied with slow, helicoidal movements from apical to coronal for 8 seconds per cycle, repeated until a total of 5 mL NaOCl had been used.

Quantitative analysis of residual gutta-percha and sealer

After final irrigant activation, canals were rinsed with 5 mL of distilled water and dried with sterile paper points. A buccolingual groove was prepared using a double-sided diamond disc, and each root was split longitudinally with a chisel and mallet, taking care not to damage the canal walls. Both root halves were examined under a Leica M320 F12 stereomicroscope (Wetzlar, Germany) at 10× magnification (Figure 1). Digital images were captured using a camera mounted on the stereomicroscope (Nikon SMZ25; Nikon, Tokyo, Japan) and transferred to a computer. ImageJ software (NIH, Bethesda, MD, USA) was used to measure the residual filling material on the canal walls. The amounts remaining in the cervical, middle, and apical thirds were calculated for each specimen and reported as a percentage of the total root canal surface area.

Measurements from both root halves were combined to determine the total root canal area and the percentage of residual material. Residual material coverage was calculated by dividing the area of remaining material by the total canal area and multiplying by 100. The mean of both halves provided a single value per tooth. To ensure measurement reliability, two examiners independently assessed all images. Any discrepancies were resolved by consensus after re-examination to minimize observer bias and enhance measurement accuracy and reproducibility.

Statistical analysis

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record

Data analysis was performed using SPSS version 23 (IBM, Armonk, NY, USA). Normality assumptions were checked using the Shapiro–Wilk test. To assess differences in residual filling material percentages across canal region, filling technique, and irrigation method, a three-way ANOVA was applied, with Tukey's HSD used for post hoc evaluation. Statistical significance was defined as a p-value less than 0.050.

Results

The percentages of residual filling material (uncleaned areas) according to the root canal filling technique, irrigant activation method, and root canal regions are presented in Table 1. The type of root canal obturation technique did not have a statistically significant effect on the amount of remaining filling material. In contrast, the effect of the irrigant activation methods on the percentage of residual filling material was statistically significant ($p < 0.001$). No statistically significant difference was found between root canal regions (cervical, middle, apical) and the percentage of residual filling material. No significant interaction was observed between the root canal filling technique and the irrigant activation method, between the filling technique and the canal region, or between the activation method and the canal region in terms of their effect on the percentage of residual filling material. Additionally, the three-way interaction among the root canal filling technique, irrigant activation method, and canal region was also not statistically significant (Table 2).

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record10

Table 1. *Descriptive statistics of the percentage of filling material remaining by root canal filling, irrigation methods and root canal regions.*

Root Canal Filling	Irrigation Method	Region			Total
		Coronal	Middle	Apical	
GP	PUI	1.67 ± 2.38	1.52 ± 2.26	3.74 ± 6.08	2.31 ± 4.04
	XP	3.02 ± 5.81	1.78 ± 2.76	1.15 ± 2.27	1.99 ± 3.93
	Laser	0.93 ± 1.36	1.08 ± 2.24	0.96 ± 2.14	0.99 ± 1.91
	Needle	2.28 ± 2.19	3.16 ± 2.34	4.48 ± 2.96	3.31 ± 2.63
	Total	1.98 ± 3.4	1.88 ± 2.48	2.58 ± 3.96	2.15 ± 3.33
BULK	PUI	1.76 ± 2.68	1.68 ± 2.65	4.44 ± 7.44	2.63 ± 4.89
	XP	2.93 ± 5.31	1.96 ± 3	1.25 ± 2.57	2.04 ± 3.8
	Laser	1.4 ± 2.76	1.19 ± 2.45	0.61 ± 1.44	1.06 ± 2.26
	Needle	2.32 ± 1.48	3.64 ± 3.92	5.06 ± 4.56	3.67 ± 3.68
	Total	2.1 ± 3.33	2.12 ± 3.13	2.84 ± 4.9	2.35 ± 3.86
Total	PUI	1.71 ± 2.49	1.6 ± 2.42	4.09 ± 6.7	2.47 ± 4.46[b]
	XP	2.98 ± 5.48	1.87 ± 2.84	1.2 ± 2.38	2.01 ± 3.85[c]
	Laser	1.16 ± 2.15	1.13 ± 2.31	0.78 ± 1.8	1.03 ± 2.08[d]
	Needle	2.3 ± 1.84	3.4 ± 3.19	4.77 ± 3.79	3.49 ± 3.18[a]
	Total	2.04 ± 336	2 ± 2.81	2.71 ± 4.44	2.25 ± 3.6

Mean ± standard deviation; a-d: There is no difference between irrigation methods with the same letter.

Table 2. *Comparison of root canal filling, irrigation method, and percentage of remaining filling material by root canal regions.*

	SS	df	MS	F	p	η^2
Root canal filling	0.25	1	0.252	0.100	0.754	0.000
Irrigation method	328.79	3	109.597	42.900	**<0.001**	0.263
Region	5.81	2	2.907	1.140	0.322	0.006
Root canal filling* Irrigation method	0.26	3	0.088	0.030	0.991	0.000
Root canal filling*Region	0.36	2	0.182	0.070	0.931	0.000
Irrigation method *Region	30.63	6	5.105	2.000	0.065	0.032
Root canal filling*Irrigation method*Region	0.86	6	0.144	0.060	0.999	0.001

SS: Sum of squares; df: Degree of freedom; MS: Mean of squares; F: Three Way Analysis of Variance; η^2 : Partial Eta Square; R^2=%28.52; Adjusted R^2=%23.95

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record11

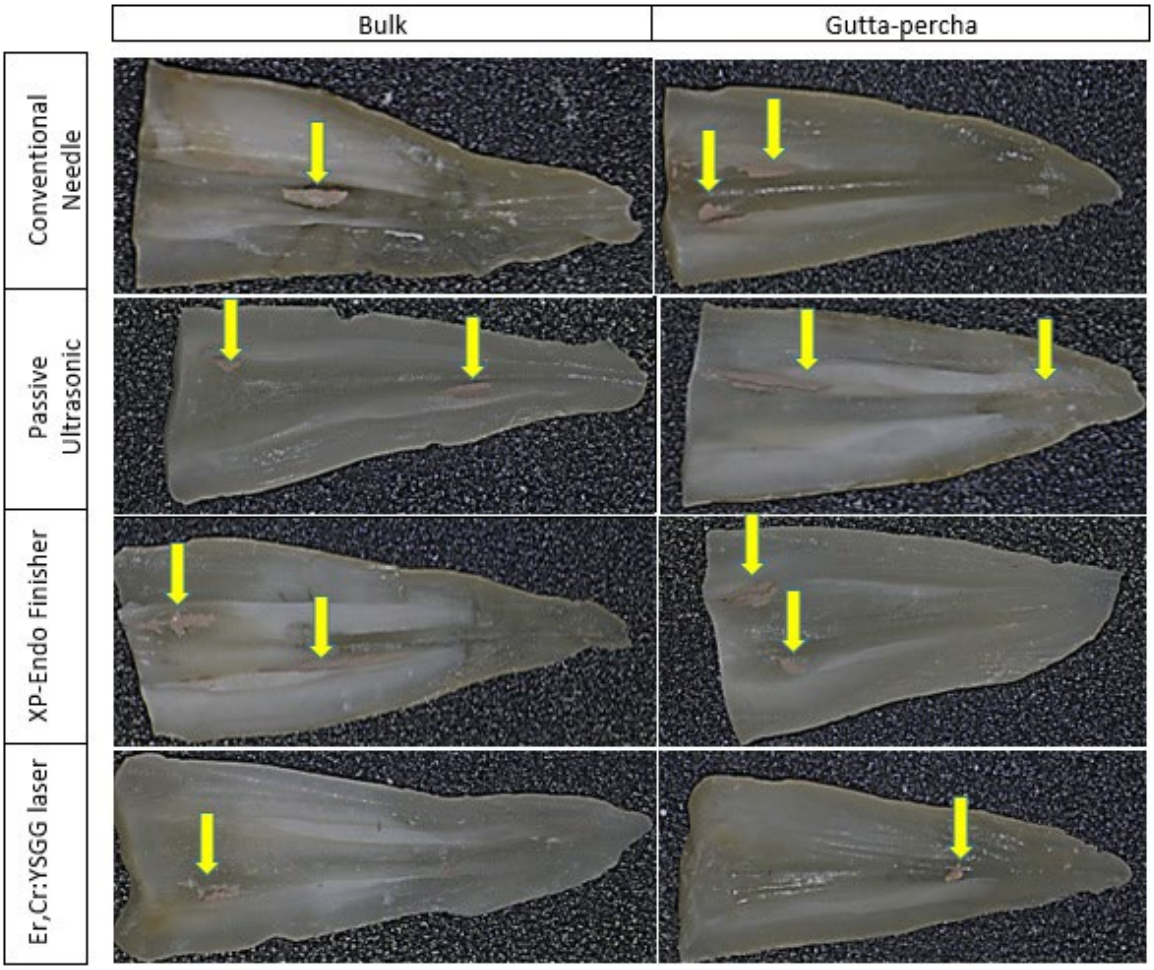

Figure 1. *Examples of microscopic image of filling material residues belong to each group. Residues are indicated by yellow arrow.*

UNDITE

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record12

Discussion

The present study investigated how effectively GuttaFlow Bioseal can be removed from root canals depending on the obturation technique used either in bulk or combined with gutta-percha, and compared the performance of four different irrigant activation methods. The primary null hypothesis stated that the retreatability of GuttaFlow Bioseal does not differ when used as a bulk fill or with gutta-percha. The results supported this hypothesis, showing that the obturation technique had no statistically significant effect on the percentage of residual filling material. The secondary hypothesis proposed that the irrigant activation method would have no significant impact on removal effectiveness. However, this hypothesis was rejected because significant differences were observed among the irrigant activation methods. Specifically, the Er,Cr:YSGG laser was the most effective technique for removing residual filling material. No statistically significant differences were found between root canal regions, and no significant interaction was observed between obturation technique, irrigant activation method, and root canal level.

The Er,Cr:YSGG laser is an infrared laser with a wavelength of 2.780 µm. Its mechanism of action is based on strong absorption by water and hydroxyapatite, producing micro-explosions in the dentin without causing carbonization or melting (15,16). Although many studies have investigated lasers for removing root canal filling materials, research specifically focused on GuttaFlow Bioseal which has seen increased clinical use, is still limited (17–20). For example, Obeid *et al.* (17) evaluated the effectiveness of a diode laser, PUI, and conventional needle irrigation in removing GuttaFlow Bioseal. They found PUI to be the most effective method. In contrast, our study showed that the Er,Cr:YSGG laser was more effective than PUI. This difference may be explained by variations in laser type and irrigation protocol.

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record13

Obeid *et al*.(17) used a diode laser with 5 seconds of active irrigation, whereas our study used an Er,Cr:YSGG laser with 8-second activation cycles.

These results align with previous findings showing that laser-assisted techniques can enhance removal of root canal residues. Kiraz *et al.* (18) reported that the laser was more effective than other methods, although no technique achieved complete removal. Similarly, Abduljalil *et al.* (19) concluded that while none of the retreatment techniques fully eliminated residual filling material, using the Er,Cr:YSGG laser improved canal cleanliness. Montero Miralles *et al.* (20) also demonstrated that the Er,Cr:YSGG laser was effective for removing debris and smear layer, and Özlek *et al.* (21) confirmed its effectiveness in removing intracanal medicaments. The present findings reinforce that the Er,Cr:YSGG laser is a highly efficient option for eliminating residual filling material from the root canal system.

In addition to laser activation, this study also confirmed the effectiveness of other irrigant activation methods. Previous studies have shown that PUI is more effective than conventional needle irrigation for retreating GuttaFlow Bioseal (13,17). Consistent with these results, the present study found significantly less residual filling material in the PUI group compared to the needle irrigation group.

Studies investigating other calcium silicate-based root canal sealers have found the XP-Endo Finisher to be more effective than PUI (20,21). The findings of this study align with those results, showing that the XP-Endo Finisher cleaned a larger canal surface area. This can be explained by its shape-memory alloy properties: above 35 °C, the instrument transitions from the martensitic to the austenitic phase, expanding up to 100 times its original diameter and adapting to complex canal geometries (8,21). PUI, by contrast, works by generating acoustic streaming and cavitation, which break up debris through fluid motion (22,23). The greater effectiveness of XP compared to PUI is likely due to its direct contact with dentin surfaces,

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record14

which PUI lacks. As supported by other studies, none of the tested protocols in this study completely removed the filling material from the root canal system (8,13,22,23).

It was also observed that the highest amount of residual filling material remained in the apical region, regardless of the activation method used consistent with previous studies (17,22). However, Pedullà *et al.* (15) reported lower residue levels in the apical region when removing GuttaFlow Bioseal. This difference may be due to their use of a larger apical preparation size (#40), compared to the #30 apical size used in the present study. Larger apical diameters can increase the effectiveness of irrigation by allowing better irrigant penetration. Although a larger apical size can improve cleaning, this study chose an apical size of #30 to minimize dentin loss, consistent with other retreatment studies (17,23). Notably, the best cleaning of the apical third in this study was observed in the laser group, although this was not statistically significant. PUI was found to be less effective in the apical region, which may be due to gas bubble formation during PUI that impedes irrigant contact and reduces cavitation effects (21).

In recent years, the bulk-fill technique has become widely preferred because it simplifies clinical procedures and saves time. Bulk-fill root canal sealers also offer advantages such as higher bond strength and improved contact with the dentin surface. Studies have reported that bulk-filled sealers demonstrate higher bond strength values than those used with core materials (24,25). However, a major drawback of the bulk technique is the potential difficulty of removing the sealer during retreatment. Eymirli *et al.* (26) evaluated the retreatability of calcium silicate-based sealers and reported that removal is more challenging when they are applied in bulk. Similarly, the present study suggests that the difficulty of removing bulk-applied sealers may be due to their interaction with dentin, although this interpretation should be approached with caution since bond strength was not directly measured.

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record15

Various methods have been used to evaluate residual filling material, including photographic analysis (8,12,27), micro-computed tomography (micro-CT) (21,28), and radiography. In this study, consistent with previous work, the roots were sectioned longitudinally and evaluated under a stereomicroscope (8,12). This method provides benefits such as standardized image distance and ease of use. While 3D methods like micro-CT provide high-resolution data, they are more expensive, time-consuming, and require advanced analysis skills. For this reason, ImageJ software was used for 2D image analysis due to its practicality and wide application in endodontic research (27,29,30). Although ImageJ is useful for two-dimensional evaluation, it cannot fully replace micro-CT. Future studies would benefit from using 3D micro-CT to achieve a more comprehensive assessment.

This study has some limitations. First, it was limited to mandibular premolars, which may reduce the generalizability of the results to other tooth types with more complex canal systems. Second, residual filling material was assessed using 2D images after root sectioning, which can alter the original canal structure and limit detail compared to advanced imaging. Lastly, the in vitro design does not account for biological factors present in clinical settings, which may influence outcomes. Future studies incorporating micro-CT and a wider range of tooth types would help strengthen the validity and clinical relevance of these findings.

Conclusion

This study demonstrated that none of the tested activation techniques were able to completely remove the bioceramic-based root canal sealer from the root canals, although all techniques significantly contributed to the reduction of residual filling material. Among the methods evaluated, the laser technique was found to be the most effective, followed by the XP-Endo Finisher and passive ultrasonic irrigation (PUI), with XP showing greater effectiveness than PUI. Based on these findings, it can be suggested that combining conventional retreatment

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record16

procedures with appropriate irrigant activation techniques may lead to more effective outcomes. Standardizing the use of such combined approaches in clinical practice could help improve the removal of residual filling materials and enhance the overall success of root canal retreatment.

Ethics committee approval: The study protocol was approved by the Institutional Review Board and Ethics Committee of the Van Yüzüncü Yıl University (21/01/2022-16).
Informed consent: Participants provided informed consent.
Peer-review: Externally peer-reviewed.

Author contributions: EO, GK participated in designing the study. GK, HG, YS participated in generating the data for the study. GK, HG, YS participated in gathering the data for the study. EO, HG participated in the analysis of the data. EO wrote the majority of the original draft of the paper. EO, GK participated in writing the paper. EO, GK, HG, YS has had access to all of the raw data of the study. EO, GK, HG, YS has reviewed the pertinent raw data on which the results and conclusions of this study are based. EO, GK, HG, YS have approved the final version of this paper. EO, GK, HG, YS guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

Conflict of interest: The authors declared that they have no conflict of interest.

Financial disclosure: The authors declared that they have received no financial support.

UNDITED PROOF

References

1. Siqueira Jr JF. Reaction of periradicular tissues to root canal treatment: benefits and drawbacks. Endod Topics 2005;10:123-47.
2. Ng YL, Mann V, Rahbaran S, Lewsey J, Gulabivala K. Outcome of primary root canal treatment: systematic review of the literature - part 1. Effects of study characteristics on probability of success. Int Endod J 2007;40:921–39.
3. Marques da Silva B, Baratto-Filho F, Leonardi DP, Henrique Borges A, Volpato L, Branco Barletta F. Effectiveness of ProTaper, D-RaCe, and Mtwo retreatment files with and without supplementary instruments in the removal of root canal filling material. Int

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record17

Endod J 2012;45:927-32.
4. Helvacioglu-Yigit D, Yilmaz A, Kiziltas-Sendur G, Aslan OS, Abbott PV. Efficacy of reciprocating and rotary systems for removing root filling material: a micro-computed tomography study. Scanning 2014;36:576-81.
5. Cavenago BC, Ordinola-Zapata R, Duarte MAH, del Carpio-Perochena AE, Villas-Bôas MH, Marciano MA, Bramante CM, Moraes IG. Efficacy of xylene and passive ultrasonic irrigation on remaining root filling material during retreatment of anatomically complex teeth. Int Endod J 2014;47:1078–83.
6. Alves FRF, Marceliano-Alves MF, Sousa JCN, Silveira SB, Provenzano JC, Siqueira JF. Removal of root canal fillings in curved canals using either reciprocating single- or rotary multi-instrument systems and a supplementary step with the XP-Endo Finisher. J Endod 2016;42:1114–9.
7. Van Der Sluis LWM, Versluis M, Wu MK, Wesselink PR. Passive ultrasonic irrigation of the root canal: a review of the literature. Int Endod J 2007;40:415–26.
8. Özyürek T, Özsezer Demiryürek E. Comparison of the effectiveness of different techniques for supportive removal of root canal filling material. Eur Endod J 2016;1:1.
9. Yamazaki R, Goya C, Yu DG, Kimura Y, Matsumoto K. Effects of Erbium,chromium:YSGG laser irradiation on root canal walls: a scanning electron microscopic and thermographic study. J Endod 2001;27:9–12.
10. Gandolfi MG, Siboni F, Prati C. Properties of a novel polysiloxane-guttapercha calcium silicate-bioglass-containing root canal sealer. Dent Mater 2016;32:e113–26.
11. Dem K, Wu Y, Kaminga AC, Dai Z, Cao X, Zhu B. The push out bond strength of polydimethylsiloxane endodontic sealers to dentin. BMC Oral Health 2019;19:1–6.
12. Al-Dahman Y, Al-Omari M. Retreatability of bioceramic and GuttaFlow bioseal root canal sealers using ProTaper universal system retreatment files: An Ex vivo study. Saudi Endod J 2021;11:42.
13. Pedullà E, Abiad RS, Conte G, Khan K, Lazaridis K, Rapisarda E, Neelakantan P. Retreatability of two hydraulic calcium silicate-based root canal sealers using rotary instrumentation with supplementary irrigant agitation protocols: a laboratory-based micro-computed tomographic analysis. Int Endod J 2019;52:1377–87.
14. Machado AG, Guilherme BPS, Provenzano JC, Marceliano Alves MF, GonÇalves LS, Siqueira JF, Neves MAS. Effects of preparation with the Self-Adjusting File, TRUShape and XP-endo Shaper systems, and a supplementary step with XP- endo Finisher R on filling material removal during retreatment of mandibular molar canals. Int Endod J 2019;52:709-715.
15. Wigdor HA, Walsh JT, Featherstone JDB, Visuri SR, Fried D, Waldvogel JL. Lasers in dentistry. Lasers Surg Med 1995;16:103–33.
16. Ateş AA, Arıcan B, Çiftçioğlu E, Küçükay ES. Influence of different irrigation regimens on the dentinal tubule penetration of a bioceramic-based root canal sealer: a confocal analysis study. Lasers Med Sci 2021;36:1771–7.
17. Obeid M, Zaghloul MES, Abdelrahmen TY. Impact of laser activated irrigation on the retrievability of Guttaflow Bioseal. BDJ Open 2024;10:72.

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record18

18. Kiraz G, Kaya B, Ocak M, Uzuner MB, Çelik HH. Micro-Ct evaluation of the removal of root filling using rotary and reciprocating systems supllemented by XP-Endo Finisher, the Self-Adjusting File, or Er,Cr:YSGG laser. Restor Dent Endo 2023;48:e36.
19. Abduljalil M, Kalender A. Efficacy of Er,Cr:YSGG Laser with different output powers on removing smear layer after retreatment of two different obturation techniques. Photobiomodul Photomed Laser Surg 2020;38:84–90.
20. Montero-Miralles P, Torres-Lagares D, Segura-Egea JJ, Serrera-Figallo MÁ, Gutierrez-Perez JL, Castillo-Dali G. Comparative study of debris and smear layer removal with EDTA and Er,Cr:YSGG laser. J Clin Exp Dent 2018;10:e598–602.
21. Özlek E, Neelakantan P, Akkol E, Gündüz H, Uçar AY, Belli S. Dentinal tubule penetration and dislocation resistance of a new bioactive root canal sealer following root canal medicament removal using sonic agitation or laser-activated ırrigation. Eur Endod J 2020;5:264–70.
22. Volponi A, Pelegrine RA, Kato AS, Stringheta CP, Lopes RT, Silva ASS, Bueno CEDS. Micro-computed tomographic assessment of supplementary cleaning techniques for removing bioceramic sealer and gutta-percha in oval canals. J Endod 2020;46:1901-1906.
23. Sümbüllü M, Ali A, Büker M, Arslan H. The efficiency of different irrigation activation techniques in the removal of calcium silicate-based endodontic sealer from artificially created groove. Aust Endod J 2023;49:238-244.
24. Crozeta BM, Silva-Sousa YT, Leoni GB, Mazzi-Chaves JF, Fantinato T, Baratto-Filho F, Sousa-Neto MD. Micro-computed tomography study of filling material removal from oval-shaped canals by using rotary, reciprocating, and adaptive motion systems. J Endod 2016;42:793–7.
25. Alsubait S, Alhathlol N, Alqedairi A, Alfawaz H. A micro-computed tomographic evaluation of retreatability of BioRoot RCS in comparison with AH Plus. Aust Endod J 2021;47:222–7.
26. Jainaen A, Palamara JEA, Messer HH. Push-out bond strengths of the dentine-sealer interface with and without a main cone. Int Endod J 2007;40:882–90.
27. Kadı G, Özlek E, Saed Y. Effect of using calcium-silicate and silicone based root canal sealers in bulk or with main core material on bond strength. J Dent Res Dent Clin Dent Prospects 2022;16:229–33.
28. Eymirli A, Sungur DD, Uyanik O, Purali N, Nagas E, Cehreli ZC. Dentinal tubule penetration and retreatability of a calcium silicate-based sealer tested in bulk or with different main core material. J Endod 2019;45:1036–40.
29. Karamifar K, Mehrasa N, Pardis P, Saghiri MA. Cleanliness of canal walls following gutta-percha removal with hand files, RaCe and RaCe Plus, XP-Endo Finisher instruments: a photographic in vitro analysis. Iran Endod J 2017;12:242–7.
30. Pedullà E, Abiad RS, Conte G, La Rosa GRM, Rapisarda E, Neelakantan P. Root fillings with a matched-taper single cone and two calcium silicate-based sealers: an analysis of voids using micro-computed tomography. Clin Oral Investig 2020;24:4487-4492.

UNEDITED PROOF

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record19