Research Square

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Efficacy of a multisonic ultracleaning system, erbium lasers and passive ultrasonic irrigation in removing calcium hydroxide from a standardized groove: an in vitro study

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Abstract

Purpose

To compare the efficacy of a multisonic ultracleaning system, an Er: YAG laser in R-SWEEPS mode, an Er, Cr: YSGG laser, passive ultrasonic irrigation, and conventional syringe-needle irrigation in removing calcium hydroxide from a standardized groove.

Methods

One hundred extracted human maxillary central incisors were prepared, and a standardized groove was cut in the apical part of the canal and filled with calcium hydroxide. After 7 days, the teeth were assigned to five groups (n = 20 each): conventional syringe-needle irrigation (SNI), passive ultrasonic irrigation (PUI), a multisonic ultracleaning system (GentleWave), an Er: YAG laser in R-SWEEPS mode, and an Er, Cr: YSGG laser. Residual calcium hydroxide was scored from 0 (empty groove) to 3 (groove completely filled) under a stereomicroscope. Data were analyzed with the Kruskal-Wallis test and Dunn's test with Bonferroni correction.

Results

The five groups differed significantly ($p < 0.001$). Syringe-needle irrigation left the most residual medicament, with 70% of specimens scored 3 and none scored 0. The multisonic system produced a clean groove in every specimen (100% scored 0), followed by the Er, Cr: YSGG laser (85%), the Er: YAG laser (75%), and passive ultrasonic irrigation (65%). Syringe-needle irrigation was significantly less effective than each of the other groups ($p < 0.001$), which did not differ from one another ($p > = 0.72$).

Conclusion

All activation systems removed calcium hydroxide more effectively than syringe-needle irrigation, with no significant differences among them. Some form of irrigant activation is therefore recommended when calcium hydroxide is removed before obturation.

Introduction

Calcium hydroxide is the intracanal medicament most often used between root canal appointments because of its high pH, antibacterial activity, and ability to dissolve necrotic tissue [1]. It is typically left in the canal for one to four weeks and must then be removed before the canal is filled. When calcium hydroxide remains on the dentin wall, it hinders sealer penetration and bonding, impairs root filling adaptation, and can increase apical leakage [2, 3]. Complete removal is therefore essential for a well-sealed root canal.

Removing calcium hydroxide completely is difficult, especially from areas instruments cannot reach, such as isthmuses, fins, and other canal-wall irregularities [4, 5]. Conventional syringe-needle irrigation leaves residual paste in these regions, prompting several activation techniques to improve cleaning [6–8]. Passive ultrasonic irrigation agitates the irrigant through acoustic streaming and cavitation and is a widely used adjunct [3, 7]. A multisonic ultracleaning system (GentleWave; Sonendo, Laguna Hills, CA, USA) has since been developed to combine a broad range of acoustic frequencies with a continuous flow of degassed irrigant to clean the root canal system without instrumentation [9, 10]. Laser-activated irrigation has also been adopted. Erbium lasers transfer energy to the irrigant via a tip, generating photoacoustic shock waves and cavitation, as in the shock-wave-enhanced emission photoacoustic streaming (SWEEPS) modality of the Er: YAG laser and the Er, Cr: YSGG laser [8, 11, 12].

Despite the growing number of activation systems, evidence on their effectiveness in removing calcium hydroxide from hard-to-reach areas is inconsistent, and direct comparisons are scarce. Most studies have tested only one or two techniques, and newer multisonic and laser-activated systems have seldom been compared with each other and with established methods under the same conditions [9–11]. The performance of a multisonic system and two different erbium lasers in removing calcium hydroxide from a standardized groove has not yet been examined together in a non-instrumentation model.

Therefore, the present study compared a multisonic ultracleaning system, an Er: YAG laser in R-SWEEPS mode, an Er, Cr: YSGG laser, passive ultrasonic irrigation, and conventional syringe-needle irrigation for removing calcium hydroxide from a standardized groove in extracted teeth. The null hypothesis was that the five techniques would not differ in the amount of residual calcium hydroxide.

Materials and methods

This in vitro study was conducted on extracted human maxillary central incisors after approval by the institutional ethics committee (approval no. 2026/2731). Teeth were collected after patients provided informed consent for their use in research.

Sample size

The sample size was estimated a priori using G*Power software (version 3.1.9.7; Heinrich-Heine-Universität, Düsseldorf, Germany) [13]. Based on the effect size from a previous study on calcium hydroxide removal [4], a large effect size (f = 0.45), an α of 0.05, and a power (1 - β) of 0.95 for comparing five groups indicated a minimum of 20 specimens per group (total N = 100).

Specimen selection and preparation

One hundred extracted human maxillary central incisors with straight roots (curvature < 5°) and closed apices were selected. Teeth with caries, cracks, fractures, calcifications, internal or external resorption, or a previous root canal treatment were excluded, and the teeth were stored in distilled water until use.

Each crown was removed under water cooling to standardize the root length to 18 mm. The canals were prepared with the VDW.ROTATE system (VDW, Munich, Germany) to size 40/.04, with 2 mL of 3% sodium hypochlorite (Cerkamed, Stalowa Wola, Poland) used for irrigation between each file. After preparation, a final rinse with 2 mL of 3% sodium hypochlorite and 2 mL of 17% EDTA (Cerkamed, Stalowa Wola, Poland) was performed.

Groove preparation and calcium hydroxide placement

Each root was embedded in silicone impression material and numbered. Longitudinal grooves were cut on the buccal and lingual surfaces, parallel to the long axis, using a diamond disc under water cooling. Each tooth was split into two halves by placing a scalpel blade into the grooves and tapping it with a mallet. A standardized groove, 4 mm long, 0.2 mm wide, and 0.5 mm deep, was prepared in the apical part of the canal wall (2–6 mm from the canal) with an ultrasonic tip to simulate residual calcium hydroxide that is inaccessible to instrumentation, as described previously [4]. Debris was removed with a brush, and the halves were rinsed with 3% sodium hypochlorite and 17% EDTA, then air-dried. Calcium hydroxide paste (UltraCal XS; Ultradent Products Inc., South Jordan, UT, USA) was applied directly from the syringe into the groove. Gutta-percha was placed in the canal to prevent cyanoacrylate from entering it, and the two halves were re-approximated and bonded with cyanoacrylate. The separation lines and the apical region were sealed with wax. A cotton pellet was placed in the access cavity, and the access was sealed with a zinc oxide-eugenol cement (Kalzinol; Dentsply Sirona, Weybridge, UK) to create a closed system. The specimens were incubated at 37°C and 100% humidity for 7 days [4] and then randomly assigned to five groups (n = 20).

Calcium hydroxide removal procedures

In the four non-GentleWave groups, 17% EDTA was used as the irrigant and delivered via a 30-gauge NaviTip needle (Ultradent Products Inc., South Jordan, UT, USA) placed 2 mm short of the working length. 2 mL was applied and activated for 20 s, and this cycle was repeated three times (total, 6 mL over 2 min). The irradiation parameters for the two laser groups are summarized in Table 1.

- **Group 1 (SNI, control)**: 17% EDTA was delivered using the 30-gauge NaviTip needle without activation (conventional syringe-needle irrigation).
- **Group 2 (PUI)**: The irrigant was activated with an IRRI 25/.00 ultrasonic tip (VDW, Munich, Germany) driven by a Newtron P5 XS BLED unit (Satelec Acteon, Merignac, France) at 40% power, with the tip positioned 2 mm short of the working length, for three 20 s cycles.
- **Group 3 (GentleWave)**: Specimens were treated with the GentleWave G4 system with ProControl (Sonendo Inc., Laguna Hills, CA, USA) using the manufacturer's procedure fluids in the following sequence: 3% sodium hypochlorite for 5 min, distilled water for 30 s, 8% EDTA for 2 min, and a final distilled-water rinse for 30 s.

- **Group 4 (R-SWEEPS)**: The irrigant was activated with a 2940 nm Er: YAG laser (LightWalker AT-S; Fotona, Ljubljana, Slovenia) in R-SWEEPS mode, using a radial tip (400 μm diameter, 14 mm length) positioned at the canal orifice, with the air and water spray off, for three 20 s cycles.
- **Group 5 (Er, Cr: YSGG)**: The irrigant was activated with a 2780 nm Er, Cr: YSGG laser (Waterlase iPlus; BIOLASE Inc., Foothill Ranch, CA, USA) in H mode, using an RFT2 radial firing tip placed 2 mm short of the working length, with the air and water spray off, for three 20 s cycles.

Outcome assessment

Outcome assessment
After activation, the two halves of each specimen were separated, and the residual calcium hydroxide in the groove was examined under a ×20 stereomicroscope with a digital camera [4]. The amount of residual medicament was scored on the four-grade scale of van der Sluis et al. [5]: 0, the groove was empty; 1, less than half of the groove was filled with residual material; 2, more than half of the groove was filled; and 3, the groove was completely filled. Two endodontists, blinded to the group allocation, scored each image independently, and each image was scored twice; inter- and intra-observer agreement (Cohen's κ) exceeded 0.90.

Statistical analysis

Cleanliness scores were reported as the median (interquartile range) and as frequencies for each score. Intergroup differences were analyzed using the Kruskal-Wallis test, followed by Dunn's test with Bonferroni correction for pairwise comparisons; the effect size was reported as epsilon-squared (ε^2). Statistical significance was set at $p < 0.05$. Analyses were performed in Python (version 3.9.6) using the SciPy (version 1.13), statsmodels (version 0.14), and scikit-posthocs (version 0.14) libraries.

Table 1
Laser irradiation parameters

Parameter	R-SWEEPS (Group 4)	Er,Cr:YSGG (Group 5)
Laser type	Er:YAG	Er,Cr:YSGG
Wavelength (nm)	2940	2780
Device	LightWalker AT-S (Fotona, Ljubljana, Slovenia)	Waterlase iPlus (BIOLASE Inc., Foothill Ranch, CA, USA)
Mode	R-SWEEPS (pulsed, paired-pulse)	H mode (pulsed)
Energy per pulse (mJ)	15	25
Frequency (Hz)	15	50
Average power (W)	0.45	1.25
Tip	Radial, 400 μm × 14 mm	RFT2 radial firing tip
Tip position	Canal orifice	2 mm short of working length
Air / water spray	Off / off	Off / off
Activation	3 × 20 s	3 × 20 s

Values are the manufacturers' preset parameters. The R-SWEEPS average power (0.45 W) reflects the paired-pulse delivery of the R-SWEEPS preset. In both laser groups the irrigant (17% EDTA) was delivered separately, and the laser was applied with the air and water spray switched off.

Results

All 100 specimens (n = 20 per group) were scored for residual calcium hydroxide, and none was excluded from the analysis. The five groups differed significantly in the amount of residual medicament remaining in the groove (Kruskal-Wallis test, $p < 0.001$; Table 2, Fig. 1).

Syringe-needle irrigation left the most residual calcium hydroxide. No specimen in this group had a completely clean groove (score 0), whereas 30% were scored 2 and 70% were scored 3 (median 3). In contrast, GentleWave produced a completely clean groove in every specimen (score 0 in 100%), followed by the Er, Cr: YSGG laser (85%), the R-SWEEPS Er: YAG laser (75%), and passive ultrasonic irrigation (65%); all four groups had a median score of 0.

Post hoc analysis showed that syringe-needle irrigation left significantly more residual calcium hydroxide than each of the other four groups (Dunn's test with Bonferroni correction, $p < 0.001$ for all comparisons). GentleWave, the R-SWEEPS Er: YAG laser, the Er, Cr: YSGG laser, and passive ultrasonic irrigation did not

differ significantly from one another ($p \geq 0.72$). No activation system left more than a minor amount of residual material (score ≤ 1) in any specimen.

Table 2
Distribution of residual calcium hydroxide cleanliness scores by group

Group	n	Score 0 n (%)	Score 1 n (%)	Score 2 n (%)	Score 3 n (%)	Median (IQR)	Sig.
SNI	20	0 (0)	0 (0)	6 (30)	14 (70)	3 (2–3)	b
PUI	20	13 (65)	7 (35)	0 (0)	0 (0)	0 (0–1)	a
GentleWave	20	20 (100)	0 (0)	0 (0)	0 (0)	0 (0–0)	a
R-SWEEPS	20	15 (75)	5 (25)	0 (0)	0 (0)	0 (0-0.25)	a
Er,Cr:YSGG	20	17 (85)	3 [18]	0 (0)	0 (0)	0 (0–0)	a

Values are n (%). The cleanliness score ranges from 0 (empty groove) to 3 (groove completely filled). Groups sharing the same superscript letter did not differ significantly (Dunn's test with Bonferroni correction, $p > 0.05$). Kruskal-Wallis $H = 69.62$, $df = 4$, $p < 0.001$, $\varepsilon^2 = 0.70$. SNI, syringe-needle irrigation; PUI, passive ultrasonic irrigation.

Figure 1

Figure 1 Distribution of residual calcium hydroxide cleanliness scores (0–3) in the five groups. Groups sharing the same letter did not differ significantly (Dunn's test with Bonferroni correction).

Discussion

In this study, we compared five methods for removing calcium hydroxide from a standardized groove that simulates an area beyond the reach of instruments. The five groups differed in residual medicament, so the null hypothesis was rejected. Conventional syringe-needle irrigation left the most residual paste, whereas the multisonic system, both erbium lasers, and passive ultrasonic irrigation removed the medicament almost completely and did not differ from one another.

A split-tooth groove model was chosen because it allows direct inspection of the residual medicament and ensures that every specimen is scored under the same conditions [5, 14]. The groove was cut in the apical part of the canal, where cleaning is most demanding [15]. EDTA was used as the irrigant in the four non-multisonic groups because sodium hypochlorite alone cannot dissolve the inorganic component of calcium hydroxide, whereas a chelating agent removes it more predictably [16, 17]. Removal depends on both chemical dissolution of the paste and its mechanical dislodgment by the agitated irrigant [18]. The medicament was removed without further instrumentation, so differences among the groups reflect the activation method rather than any added mechanical action.

Syringe-needle irrigation was the least effective method, and no specimen in this group showed a clean groove. This finding is consistent with earlier work showing that conventional irrigation left more calcium hydroxide than activated techniques [2, 3, 6, 8, 19]. When the irrigant is not agitated, it does not exchange within the groove and cannot reach the residual paste, which explains the result [3, 7].

The four activated groups behaved similarly and cleaned the groove almost completely. Passive ultrasonic irrigation has long been reported to improve calcium hydroxide removal through acoustic streaming and cavitation, which drive the irrigant into canal-wall irregularities [3, 7, 20, 21]. The two erbium lasers were as effective as the ultrasonic and multisonic systems. Er: YAG and Er, Cr: YSGG lasers transfer energy to the irrigant, producing photoacoustic shock waves and cavitation bubbles that agitate the fluid [22]. The Er: YAG laser was applied in the R-SWEEPS mode, in which paired, synchronized pulses amplify the shock waves generated in the irrigant and reinforce photoacoustic streaming through the canal; this mode has effectively removed calcium hydroxide and other medicaments from simulated defects in earlier work [8, 12]. Gündoğar et al. [11] compared the same modalities and reported the least residual material with the multisonic system, followed by the Er: YAG and Er, Cr: YSGG lasers, then ultrasonic and needle irrigation, a ranking that matches the order seen here, even though the activated groups did not differ significantly.

The multisonic system produced a clean groove in every specimen. The GentleWave G4 used here achieved near-complete calcium hydroxide removal, comparable to results reported for earlier versions of the system [9, 10, 23, 24]. The system maintains a continuous flow of degassed irrigant at about 45 mL/min and operates across a broad range of acoustic frequencies [9, 10], delivering a much larger volume of fresh solution to the canal than the other techniques, which used 6 mL of irrigant over 2 min. This greater irrigant volume and flow, rather than the activation mechanism alone, may partly account for the complete clearance obtained with the multisonic system. Several early studies concluded that no technique removed the medicament completely [3, 4], so the full clearance seen here, together with the small amount left by the other activated methods, probably also reflects the accessible geometry of the standardized groove. Once the irrigant is agitated, the shallow groove is reached by any of these systems. This ceiling effect may explain why the multisonic system, although it cleaned every specimen, was not statistically superior to the lasers or to ultrasonic irrigation.

Clinically, these findings suggest that some form of irrigant activation, rather than syringe irrigation alone, should be used when removing calcium hydroxide before obturation. For an accessible defect, the choice among multisonic, laser, and ultrasonic activation may depend more on availability and cost than on cleaning efficacy.

Limitations

This study has several limitations. As an in vitro experiment on a standardized groove, it cannot replicate the irregular shape of a true internal resorption defect or the complexity of the entire root canal system, so the results should not be applied directly to clinical practice [14, 15]. The multisonic group was

treated with the manufacturer's procedure fluids (3% sodium hypochlorite and 8% EDTA) delivered as a continuous flow of about 45 mL/min, whereas the other groups received 6 mL of 17% EDTA over 2 min. Thus, the irrigant, total volume, flow rate, and exposure time differed between the multisonic system and the remaining groups, which may have favored the multisonic system. Because all activated systems produced near-complete cleaning, the absence of differences among them reflects a ceiling effect and should not be interpreted as evidence of equivalence. Residual calcium hydroxide was graded using an ordinal four-point score under a stereomicroscope rather than measured volumetrically, which limits the resolution of the outcome. Laser-activated and multisonic irrigation can also extrude irrigant or debris beyond the apex, which was not assessed here [25]. Finally, the antibacterial effect and the influence of residual medicament on the seal of the root filling were not evaluated.

Future studies should test these systems in more complex, clinically representative models, match the irrigant and exposure time across groups, and examine how residual calcium hydroxide affects the quality of the root filling and treatment outcome.

Conclusion

Within the limitations of this in vitro study, all the activation systems tested, namely the multisonic ultracleaning system, the Er: YAG laser in R-SWEEPS mode, the Er, Cr: YSGG laser, and passive ultrasonic irrigation, removed calcium hydroxide from the standardized groove more effectively than conventional syringe-needle irrigation. The activation systems did not differ from one another, so none of them can be regarded as superior for this purpose.

Declarations

Competing interests:

The authors declare no competing interests.

Ethics approval:

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the institutional ethics committee (No. 2026/2731).

Consent to participate:

Written informed consent was obtained from the patients for the use of their extracted teeth in research.

Consent to publish:

Not applicable.

Clinical trial number

Not applicable.

AI Declaration

During the preparation of this work, the authors used a large language model to assist with statistical analysis and with drafting and language editing of the manuscript. The authors reviewed and edited the content as needed and take full responsibility for the manuscript's content.

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Author Contribution

T.Ö. Conceptualization, Methodology, Supervision, Writing - review and editing. M.G. Methodology, Investigation, Writing - review and editing. O.Ö. Investigation, Data curation. A.A. Formal analysis, Writing - original draft. H.Ö. Data curation, Writing - review and editing.

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Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Figures

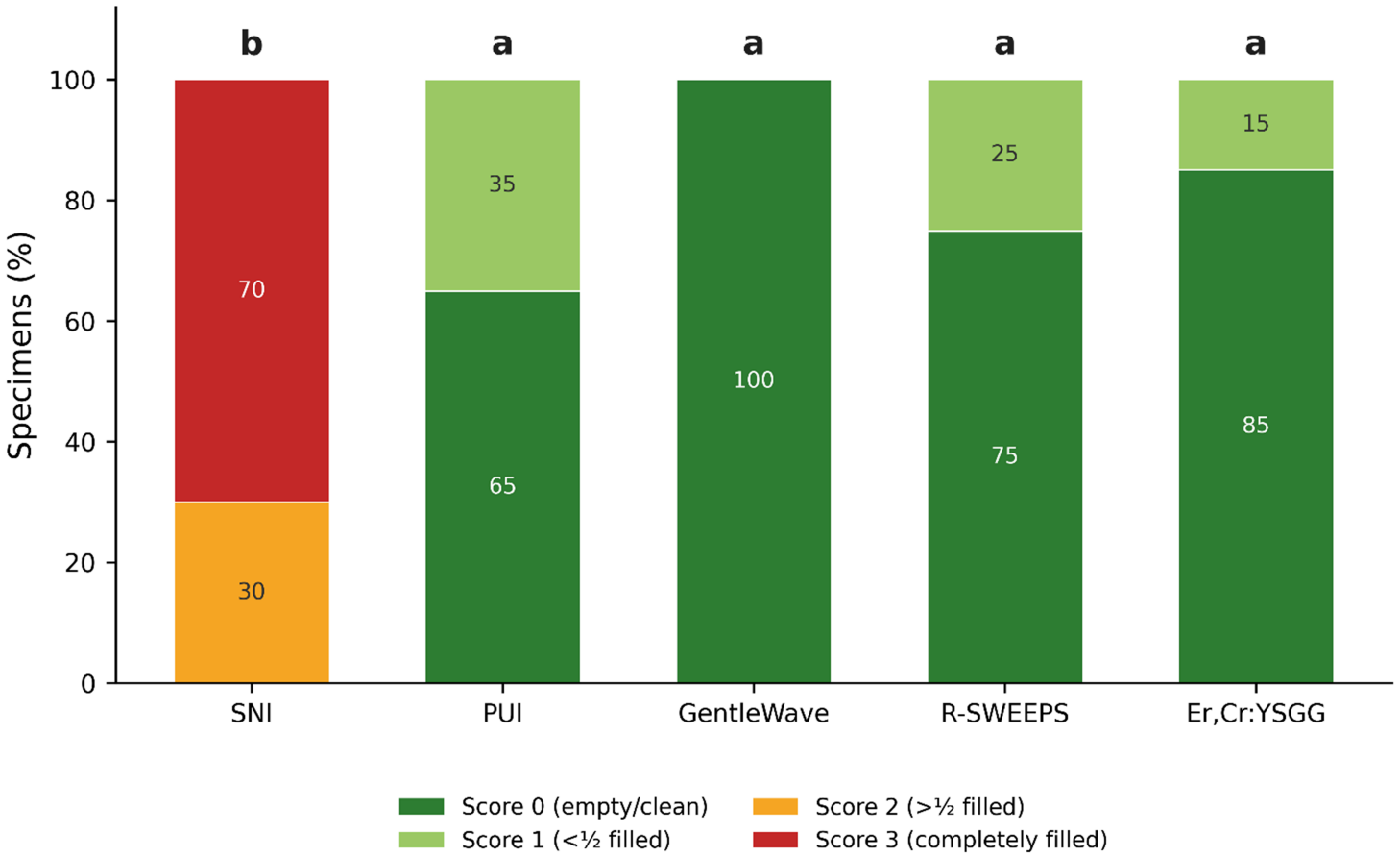


Figure 1

Distribution of residual calcium hydroxide cleanliness scores (0-3) in the five groups. Groups sharing the same letter did not differ significantly (Dunn's test with Bonferroni correction).