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Review Article

A Systematic Review on Endodontic Retreatment and the Effective Removal of Endodontic Sealers Using Lasers

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ABSTRACT

Several studies have investigated the ability of lasers to enhance the performance of irrigants within the root canals. Laser-activated irrigation (LAI) has been shown to outperform traditional methods in cleaning the canal and removing the smear layer. When compared to conventional irrigant agitation techniques, lasers offer clear advantages. The present review study aimed to investigate the effective removal of endodontic retreatment and endodontic sealers using lasers. A systematic review of the literature from 2010 to 2022 was conducted using databases such as Medline, PubMed, and ScienceDirect, with keywords including "endodontic retreatment," "sealer removal," and "lasers." The PRISMA flowchart was used to illustrate the article selection process. Out of the 9 studies reviewed, 4 studies did not show a significant difference in sealer removal with or without lasers. However, the remaining 5 studies showed a significant improvement in the removal of sealer residue from the root canals. This suggests that lasers are an effective tool for removing most of the residual sealing materials from the root canals.

Keywords: Systematic review, Sealers, Endodontics retreatment, Lasers

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Introduction

Traditional endodontic practices utilize various methods to activate irrigants to enhance cleaning and sealer penetration, contributing to successful outcomes. Research has demonstrated that agitation of irrigants can speed up tissue disintegration and boost the effectiveness of irrigation solutions. Several techniques are available for this purpose, including manual methods like Endobrush agitation, manual-dynamic agitation, and needle or cannula irrigation, as well as mechanical approaches such as continuous irrigation during rotary instrumentation, rotating brush agitation, and ultrasonic or sonic methods [1].

The application of lasers to stimulate irrigants within root canals has been the subject of numerous research [2]. Laser-activated irrigation (LAI) has proven to be more efficient than traditional methods in cleaning the canal and eliminating the smear layer. When compared to other forms of irrigant agitation, lasers offer distinct advantages. After obturation, lasers provide an effective way to remove debris, the smear layer, and other particles, in addition to offering disinfecting benefits. The biological effects of lasers, including photothermal, photomechanical, photochemical, and photoacoustic effects, occur when different laser wavelengths interact with various targets such as dentin, bacteria, and irrigants [3, 4]. The smear layer, which consists of inorganic residues, organic pulp tissue, odontoblastic processes, and microorganisms with their metabolic byproducts, can reduce the ability of intracanal disinfectants and sealers to permeate the dentinal tubules. This layer can remain in the dentinal tubules for up to 40 µm. Studies have shown that removing the smear layer is essential for improving the adhesion of sealers to the canal walls, which enhances the overall prognosis of the treatment [4, 5].

Recently, there has been a growing focus within the research community on developing novel methods for activating irrigation systems. The photochemical, photothermal, and photoacoustic effects of dental lasers are being actively explored. The primary goal behind utilizing LAI is to enhance the performance of irrigation techniques. One such advancement is photon-induced photoacoustic streaming (PIPS), which is achieved with an Er: YAG laser. This innovative method of irrigant activation has been shown to improve root canal cleaning and increase the adherence of resin sealers during endodontic procedures. This suggests that activating the irrigant to create streaming significantly strengthens the bond of resin-based sealers [6-16]. For example, the application of a laser was found to enhance the effectiveness of the AH Plus sealer [6].

The present review study aimed to investigate the effective removal of endodontic retreatment and endodontic sealers using lasers.

Materials and Methods

A comprehensive review of the literature published between 2010 and 2022 was conducted using databases such as Medline, PubMed, and ScienceDirect. The search terms included "sealer removal," "endodontic retreatment," and "lasers" **(Table 1)**. Additionally, the PRISMA flowchart was employed to outline the process of selecting the relevant articles from the search results **(Figure 1)**.

Table 1. Inclusion and exclusion criteria

№	Inclusion criteria	Exclusion criteria
1.	Studies with case-control and randomized controlled trial designs	Reviews, meta-analyses, expert viewpoints, or narrative overviews
2.	Published within the timeframe of 2010 to 2022	Outside the designated time frame
4.	Publications in the English language	Non-English language
7.	In vivo (humans)	In vitro

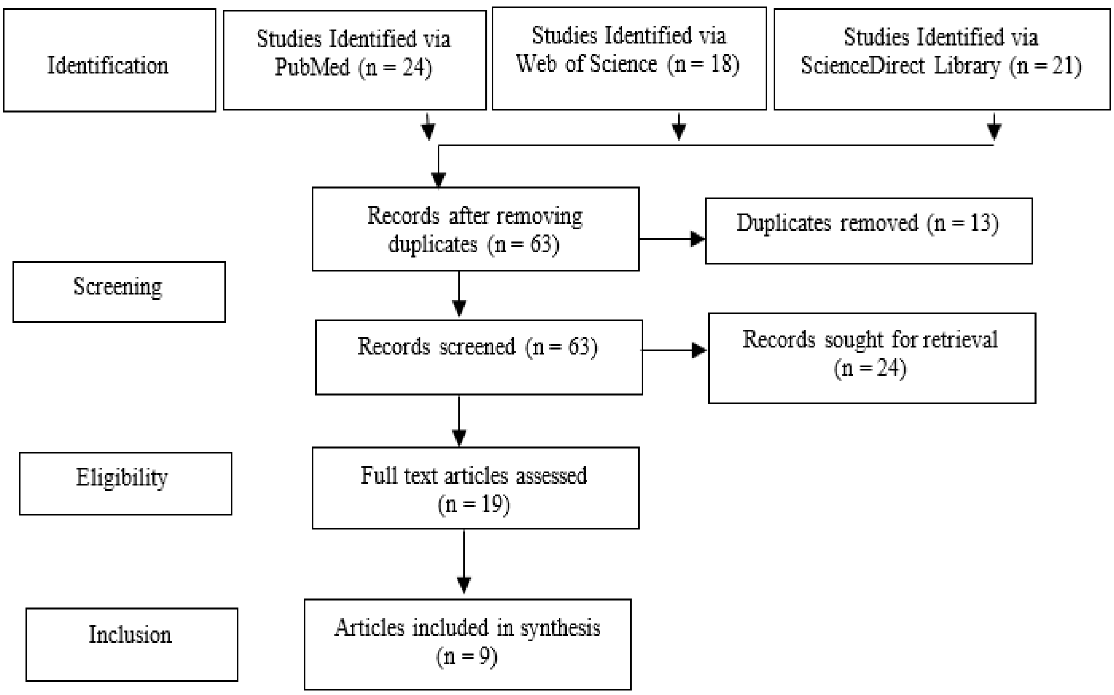

Figure 1. PRISMA flow diagram

Risk of bias assessment

The quality of the studies was evaluated using the Cochrane risk of bias assessment tool **(Table 2)**.

Table 2. Summary of Cochrane risk of bias assessment

Study	Selection Bias/Appropriate control selection/baseline characteristics similarity	Selection bias in randomization	Selection bias in allocation concealment	Performance-related bias in blinding	Reporting bias/Selective reporting of outcomes	Detection bias Blinding outcome assessors	Accounting for confounding bias
Lloyd *et al.* [7]	+	+	-	+	+	+	-
ElShafei *et al.* [8]	+	+	+	+	+	+	-
Suk *et al.* [10]	+	+	+	+	+	_	+
Keleş *et al.* [11]	+	+	+	+	+	+	-
Nasher *et al.* [12]	+	-	+	+	+	-	+
Eldeeb *et al.* [13]	+	+	+	-	+	+	+
Yang *et al.* [14]	+	+	-	+	+	+	+
Dönmez *et al.* [15]	+	+	+	+	+	+	-
Laky *et al.* [16]	+	+	-	+	+	+	+

Results and Discussion

In their 2016 study, Lloyd *et al*. [7] assessed the effectiveness of three distinct irrigation methods: Er: Passive ultrasonic irrigation (PUI) using EndoUltra, YAG LAI (PIPS), and conventional needle irrigation (SNI) for eliminating calcium hydroxide [Ca(OH)2] from the mesial roots of Weine Type II mandibular molars. The researchers employed CT scanning to examine the mesial roots, which had complex intra-canal structures and a shared apical foramen, in thirty mandibular molars. Before the removal process, the mean volume of Ca(OH)2 was notably higher in the coronal third compared to the middle and apical thirds ($P < 0.001$). The effectiveness of Ca(OH)2 removal from the coronal and middle thirds was similar across all three methods ($P > 0.05$). However, in the apical third, PIPS demonstrated significantly better Ca(OH)2 clearance (median 0%; IQR: 0-0) than both PUI and SNI ($P < 0.001$).

In a 2022 study, ElShafei *et al*. [8] explored the effectiveness of PIPS on push-out bond strength, sealer penetration, and smear layer removal, using a 2940 nm Er: YAG laser and a 980 nm diode laser. The research was conducted on 60 permanent human teeth, each containing a single canal. Results regarding smear layer removal indicated that the PIPS group achieved the best exposure of dentinal tubules, followed by the diode laser group, while the Side-vented needle group showed the least effectiveness. Significant differences were noted between the groups in terms of sealing and dye penetration, with the Er: YAG laser (PIPS) being the most successful. Although no significant difference was observed in push-out bond strength between the diode and Er: YAG groups, both showed a considerable improvement over the Side-vented needle group. The study concluded that activation of the diode or Er: YAG laser (PIPS) led to better irrigant penetration and smear layer reduction, which in turn enhanced sealer penetration, sealing, and bond strength in endodontically treated teeth [9].

In their 2017 study, Suk *et al*. [10] examined the effectiveness of PIPS in removing residual filling material from root canals following the rotational phase of retreatment. The study involved 46 single-rooted human teeth that were extracted and prepared. After applying PIPS, there was a significant reduction in the remaining filling material across all groups ($P < 0.05$). MTA Fillapex was the easiest to remove during the rotating phase of retreatment. Post-rotary phase, no significant differences were observed between the EndoSequence BC and AH Plus groups in terms of the amount of remaining filling material. Overall, PIPS enhanced the removal of filling residues in all groups.

Keleş *et al*. [11] used micro-computed tomography to assess the effectiveness of lasers in removing remaining filling materials from oval-shaped root canals after retreatment procedures involving rotary instruments. 42 mandibular canine teeth were selected, and their root canals were disinfected and cleaned. The amount of residual filling material was analyzed before and after laser treatment using the matched sample t-test and one-way analysis of variance within and between groups. The Er: YAG laser group showed a significantly higher removal rate (13%) compared to the Er: YAG laser group (4%), the Nd: YAG group (3%), and the control group (0%). In conclusion, none of the retreatment techniques fully eliminated the filling materials. However, after using rotary tools, lasers proved to be more effective in removing any remaining filling materials.

Nasher *et al*. [12] evaluated the effectiveness of different irrigants in eliminating the endodontic smear layer using the Er: YAG PIPS technique (2.94 µm). A total of 64 single-rooted teeth were randomly allocated into 8 groups (a-h; n=8) for endodontic treatments up to size #40. In groups b, c, f, and g, the smear layer was present in the coronal, middle, and apical thirds, while in groups a, d, e, and h, dentinal tubules in the coronal and middle thirds were open, but the apical third remained unaffected. No statistically significant differences ($P > 0.0018$) were observed between the groups that received only irrigants and those that received both irrigants and Er: YAG PIPS. The study concluded that the Er: YAG PIPS method was not more effective than irrigants alone in smear layer removal.

In the 2021 research by Eldeeb *et al*. the goal was to compare the effectiveness of different equipment tapers in removing the smear layer and enhancing sealer penetration using photon-initiated photoacoustic streaming (PIPS) in root canals [13]. The study involved 120 mandibular molars, which were divided into three groups based on the taper of their apical preparations. Sealer penetration was analyzed using three-way ANOVA and Tukey's post hoc test. PIPS activation led to a significant reduction in the smear layer and improved sealer penetration ($P < 0.001$) across all thirds of the root. However, no significant differences ($P > 0.05$) were found between the two irrigation techniques regarding sealer penetration in the apical third after preparing the root canal to a 25/4% taper.

In research by Yang *et al*. [14], micro-CT was used to compare the effectiveness of PIPS, ultrasonically activated irrigation (UAI), and shock wave-enhanced photoacoustic emission streaming (SWEEPS) in removing accumulated hard-tissue debris (AHTD) from the root canal system of mandibular molars. Thirty mandibular first and second molars, each with isthmuses connecting the mesial root canals to a single distal canal, were scanned three times. Canal volumes before and after instrumentation and the volumes of debris remaining after preparation were similar across the groups ($P > 0.05$). The SWEEPS group showed the most significant debris reduction in the mesial canals, with a decrease of 84.31%, much higher than the reductions seen with PIPS (58.79%) and UAI (50.2%). In the distal canals, no significant difference in debris removal was observed between PIPS and UAI ($P > 0.05$). However, significant differences were found when comparing the UAI and SWEEPS groups ($P < 0.05$) as well as PIPS and SWEEPS. Ultimately, SWEEPS was more efficient in removing AHTD than both PIPS and UAI.

Dönmez *et al*. [15] evaluated the performance of 2 nickel-titanium rotary systems, one using LAI, during the retreatment process. 60 human mandibular premolars were instrumented with K-files up to size 35. The amount of remaining filling material showed no significant difference between the groups ($v2 = 0.754$; $P = 0.86$). Thus, there was no noticeable difference in the ability of the HyFlex EDM and PTR systems to eliminate residual filler. Additionally, the PIPS method did not contribute significantly to the removal of leftover filler material in either rotary system group.

In the study by Laky *et al*. [16], the effectiveness of calcium hydroxide removal from root canals using PIPS was compared to traditional needle irrigation and sonic-assisted irrigation. 60 artificial teeth were prepared by filling them with calcium hydroxide and then divided into four groups for treatment. The groups were assigned to receive either needle irrigation, sonic irrigation, PIPS with a lower energy setting (10 mJ, 15 Hz), or PIPS with a higher energy setting (25 mJ, 40 Hz). The apical extrusion was monitored by observing color changes in agarose gel, which were digitally analyzed using Photoshop. The results showed no significant difference in calcium hydroxide removal between the 2 laser groups. However, ultrasonic irrigation led to much greater calcium hydroxide removal compared to needle irrigation. Both PIPS groups (regardless of energy setting) showed a significant advantage over needle irrigation and sonic-assisted irrigation in terms of calcium hydroxide removal. In terms of apical extrusion, the group treated with the highest laser setting (25 mJ/40 Hz) produced the most noticeable color change in the periapical gel. Notably, PIPS at the 10 mJ/15 Hz setting was effective in removing calcium hydroxide without increasing the apical extrusion of the irrigating solution. The summary of findings from the included studies is presented in **Table 3**.

Table 3. Summary of findings from the included studies

Author's name	specimens	Objective	Techniques	Outcome
Lloyd *et al.* [7]	30	This study assessed the effectiveness of three distinct irrigation techniques—Er: YAG LAI (PIPS), passive ultrasonic irrigation (PUI) with EndoUltra, and standard needle irrigation (SNI)—in removing calcium hydroxide [Ca(OH)2] from the mesial roots of Weine Type II mandibular molars.	PIPS, PUI, SNI	The clearance of Ca(OH)2 in the apical third was notably higher with PIPS compared to PUI and SNI ($P < 0.001$).
ElShafei *et al.* [8]	60	This research aimed to evaluate the effectiveness of PIPS, utilizing a 2940 nm Er: YAG laser and a 980 nm diode laser, for the removal of the smear layer.	2940 nm Er: YAG laser and a 980 nm diode laser	When the diode or Er: YAG laser (PIPS) was used for irrigation activation, it led to enhanced irrigant penetration and better reduction of the smear layer.
Suk *et al.* [10]	36	This investigation focused on assessing the efficiency of photon-initiated photoacoustic streaming (PIPS) in eliminating filling remnants from root canals during the rotational phase of retreatment.	PIPS	Following the rotary phase of retreatment, the quantity of remaining filling material in the EndoSequence BC and AH Plus groups did not differ from the initial amount. However, PIPS improved the removal of remnants in all groups.
Keleş *et al.* [11]	42	The goal of this study was to explore how effectively lasers can remove remaining filling material from oval-shaped canals following retreatment procedures using rotary tools.	Micro-computed tomographic imaging, Er: YAG laser and Nd: YAG	A comparison between the groups showed that Er: YAG laser application after rotary instrumentation removed a significantly larger amount of filling material (13%) compared to Er: YAG laser-based PIPS (4%) and Nd: YAG (3%) ($P < 0.05$).
Nasher *et al.* [12]	64	This research compared the ability of the Er: YAG PIPS technique to remove the endodontic smear layer relative to other irrigation methods.	Er: YAG PIPS	No significant difference was observed between the groups treated with only irrigants and those treated with Er: YAG PIPS along with the same irrigants.
Eldeeb *et al.* [13]	120	The objective of this study was to examine the effect of photon-initiated photoacoustic streaming (PIPS) on the performance of irrigation in root canals with different instrumentation tapers in terms of smear layer removal.	Three-way analysis of variance (ANOVA)	PIPS activation resulted in significantly higher reductions in the smear layer and increased sealer penetration ($P < 0.001$).
Yang *et al.* [14]	30	This study aimed to compare the efficacy of ultrasonically activated irrigation (UAI), PIPS, and SWEEPS activation for removing accumulated hard-tissue debris (AHTD).	Micro-CT scans, UAI, PIPS, SWEEPS.	There was no significant difference in canal volume before or after instrumentation across the three groups. The debris volume after canal preparation showed no substantial variation ($P > 0.05$).

Dönmez *et al.* [15]	60	The effectiveness of two different nickel-titanium rotary systems in retreatment procedures with and without LAI was evaluated.	HyFlex EDM and PTR systems, PIPS	The PIPS method did not provide any significant added benefit for removing filling material across all rotary systems tested.
Laky *et al.* [16]	60	The study compared the removal of calcium hydroxide from the root canal using PIPS with needle irrigation and sonic-activated irrigation techniques.	Needle irrigation and irrigation utilizing sonic activation	PIPS at 10 mJ/15 Hz achieved almost complete removal of calcium hydroxide without causing an increase in apical extrusion of the irrigation fluid.

The PIPS tip remains within the access cavity, unlike SNI and PUI, which generate cavitational bubbles that travel as shear forces along the canal walls. In mandibular molars with Weine Type II canal morphology and isthmuses, no signs of Ca (OH)2 were detected in any part of the root canal system. The absence of Ca (OH)2 was observed throughout the canal, including in the tip, where irrigation often proves more challenging. These results may be linked to the higher average fluid velocity in the middle and upper thirds of the structure. The test samples also featured Weine Type II canal systems, which promote fluid exchange in a circular motion between the mesiobuccal and mesiolingual canals. The canal's natural structure may have aided in the removal of Ca (OH)2 from the apical third by facilitating greater fluid movement and stronger shear stresses [17].

Lasers are predominantly used in endodontic irrigation, with their application having been refined over time through the use of different laser types. They offer potential benefits for root canal therapy, apical surgery, pulp preservation, and other endodontic procedures in the future [17]. Various lasers, including Diode 980 nm, Er: YAG, Nd: YAG, and CO2, are effective for eliminating the smear layer, eradicating bacteria, and sealing wounds. However, there remains a lack of comprehensive studies, highlighting the need for further clinical research to establish a scientific basis for the use of specialized lasers in endodontics [18, 19].

Only 2 researchers [11, 20] have investigated the use of PIPS for removing epoxy resin-based sealant in root canal retreatment. Keles *et al.* evaluated the effectiveness of PIPS, LAI with an Er: YAG, and laser-assisted removal using an Nd: YAG for clearing AH Plus and gutta-percha after rotational retreatment. While all methods significantly improved debris removal, the most effective approach involved positioning the fiber tip deep within the canal, approximately three millimeters from the WL. In another study, Jiang *et al.* [21] compared PIPS to passive ultrasonic irrigation and sonic irrigation for eliminating AH Plus during ProTaper retreatment, concluding that PIPS demonstrated superior performance.

The current study observed that laser application considerably reduced the amount of filler material requiring removal when using R-Endo rotary instruments during retreatment. Among the different methods examined, the Er: YAG laser achieved the highest percentage of filler removal compared to Er: YAG laser-based PIPS and Nd: YAG laser techniques, leading to the rejection of the initial hypothesis. Unlike Nd: YAG lasers, Er: YAG lasers function through a photomechanical interaction that incorporates photothermal and photoablation mechanisms, primarily facilitated by water [22]. However, the potential for filler material carbonization because of the photothermal effect remains a consideration [23].

Multiple studies [24, 25] have demonstrated the effectiveness of Er: YAG PIPS in eliminating the endodontic smear layer. Findings suggest that activating 5% NaOCl and 17% EDTA with the Er: YAG PIPS technique enhances the performance of irrigants, particularly in clearing the smear layer from the apical third of the canal walls. However, results from this study indicated that the PIPS approach did not lead to an improvement in smear layer removal efficiency.

Compared to PI, the PIPS technique proved to be more effective in eliminating the smear layer across all tested samples. Additionally, sealer penetration was significantly higher following PIPS use than with PI. The increased effect of EDTA observed with PIPS may explain the greater sealer penetration, as the intensified agitation improved EDTA's action on the dentin surface, thereby increasing permeability [26]. This could be attributed to the superior smear layer removal capability of high-powered lasers or a shift in the inorganic-to-organic composition of root dentin [27].

When comparing SWEEPS and PIPS, researchers found that SWEEPS was more effective in flushing AHTD from root canals. The SWEEPS technology utilizes synchronized laser pulses to amplify shock waves generated by collapsing bubbles in confined spaces such as root canals. In clearing debris from artificial canal irregularities, PIPS outperformed UAI. However, data from sectioning techniques assessing debris removal in the main canal and isthmus revealed no important difference between PIPS and UAI [28].

In the present study, using the PIPS method for additional cleaning did not impact the volume of residual filling material compared to conventional needle irrigation. Similar results were reported by Martins *et al*. [29], who evaluated sonic and ultrasonic irrigation as supplementary techniques, supporting these findings. Although retreatment with rotary instruments proved effective in eliminating filling material, Kelesx *et al*. [11] concluded that incorporating PIPS as an adjunctive approach yielded better results. In the AH Plus group, supplemental removal was achieved using XP-endo Finisher R. However, a different study indicated that this effect was not observed in the TotaFill BC Sealer group.

Calcium hydroxide was almost eliminated when using PIPS at both power settings. Li *et al*. [30] similarly reported that PIPS achieved a 99% success rate in calcium hydroxide removal, while needle irrigation was effective in 81% of cases. The present study aligns with these findings, demonstrating near-complete removal of calcium hydroxide in the PIPS groups, 90% removal in the sonic group, and 70% in the needle irrigation group. Multiple studies [31-33] have indicated that needle irrigation is less efficient at removing calcium hydroxide compared to other techniques, including passive ultrasonic irrigation, the EndoActivator, and the Rinsendo.

Conclusion

Among the nine studies analyzed, four reported no significant difference in sealer removal with or without laser application. In contrast, the remaining five studies demonstrated a notable improvement in eliminating residual sealer from root canals. These findings suggest that lasers can effectively aid in the removal of most remaining sealing materials.

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