CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Laser Assisted Endodontics therapy: Activated irrigation through Laser technologies, an integrative systematic review

Joseph Issam Olivier Ibimbou

Dissertação conducente ao **Grau de Mestre** em **Medicina Dentária (Ciclo Integrado)**

—

Gandra, **maio de 2024**

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Joseph Issam Olivier Ibimbou

Dissertação conducente ao **Grau de Mestre** em **Medicina Dentária (Ciclo Integrado)**

Laser Assisted Endodontics therapy: Activated irrigation through Laser technologies, an integrative systematic review

Trabalho realizado sob a Orientação do
Professor Doutor Fausto Miguel Tadeu Coelho Da Silva

DECLARAÇÃO DE INTEGRIDADE

Eu, Joseph Issam Olivier Ibimbou, declaro ter atuado com absoluta integridade na elaboração deste trabalho, confirmo que em todo o trabalho conducente à sua elaboração não recorri a qualquer forma de falsificação de resultados ou à prática de plágio (ato pelo qual um indivíduo, mesmo por omissão, assume a autoria do trabalho intelectual pertencente a outrem, na sua totalidade ou em partes dele). Mais declaro que todas as frases que retirei de trabalhos anteriores pertencentes a outros autores foram referenciadas ou redigidas com novas palavras, tendo neste caso colocado a citação da fonte bibliográfica.

Acknowledgments

I would like to thank CESPU University for this wonderful opportunity, which turned out to be an amazing experience.

To my supervisor, Professor Fausto Miguel Tadeu Coelho Da Silva.

My dear people, close friend and family, thank you for all the great - and thankfully only very few bad - moments enjoyed together, the support and the love.

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

RESUMO

Introdução: O tratamento do sistema de canais radicular visa eliminar a carga microbiana da raiz e prevenir a sua reinfeção. A *smear layer*, produzida pela instrumentação impede a ação correta das soluções de irrigantes e da obturação do canal radicular. O NaOCl é excelente na desinfeção do canal radicular, mas não elimina completamente a *smear layer*. A irrigação com seringa e agulha tem um efeito limitado no terço apical do canal. Assim, dispositivos sónicos, ultrassónicos e laser foram desenvolvidos para melhorar o efeito do irrigante. O laser produz uma onda de choque fotoacústica que proporciona uma melhor remoção da *smear layer*, detritos e bactérias do canal radicular.

Objetivo: Esta revisão sistemática integrativa avalia se a ativação dos irrigantes com laser é mais eficaz do que a irrigação tradicional na desinfeção do sistema de canais radiculares e na remoção de detritos e *smear layer*.

Materiais e métodos: Foi realizada uma pesquisa bibliográfica nas bases de dados PubMed e ScienceDirect, utilizando as palavras-chave; laser, root, canal, irrigants. A pesquisa foi realizada entre abril de 2023 e fevereiro de 2024.

Resultados: 211 artigos foram identificados, e após uma análise rigorosa com submissão aos critérios de inclusão e exclusão, foram selecionados 15 artigos científicos publicados nos últimos 10 anos.

Discussão: No terço apical, o laser melhorou a capacidade de desinfeção e a remoção de *smear layer*. Também permite uma melhor penetração dos irrigantes e dos materiais de obturação nos túbulos dentinários.

Conclusão: <u>Nesta revisão sistemática integrativa, verificou-se que o laser é mais eficaz que outras técnicas de ativação na desinfeção de canal.</u>

Palavras-chave:"laser","root","canal","irrigants"

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

ABSTRACT

Introduction: Root canal treatment aim to eliminate the root microbial load and prevent its reinfection. RCP produces the Smear layer, a negative factor in correct action of the irrigation solutions and root canal obturation. NaOCl is excellent in root canal disinfection, but can't completely remove the smear layer, even combined with EDTA. Traditionally performed with a syringe-needle combination, irrigation as limited effect on apical third and complex anatomy of the canal. Thus, sonic, ultrasonic and laser devices were developed to improve irrigant effect. LAI produce a photoacoustic shockwave which provide a better removal of smear layer, debris and bacteria from the root canal walls.

Objective: This integrative systematic review evaluates if activating an irrigation solution with a laser is more effective than traditional irrigation methods in disinfecting the root canal system, removing debris and smear layer.

Materials and methods: A Literature search was performed in the PubMed, and ScienceDirect databases, using the following keywords: laser, root, canal, irrigants. The search was carried out between April 2023 and February 2024.

Results: 211 articles were identified and after a rigorous analysis with submission to the inclusion and exclusion criteria, 15 scientific articles published within 10 years were selected.

Discussion: In the apical third, laser devices improved disinfection power and smear layer removal. It also allows a better penetration of irrigation solution and sealer materials in dentinal tubules.

Conclusion: <u>In this integrative systematic review it was verified that the laser was more effective than other activation techniques in disinfecting root canals.</u>
Keywords: " laser ", "root ","canal", " irrigants ".

GENERAL INDEX

INDEX OF TABLES

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

INDEX OF FIGURES

INDEX OF ACRONYMS AND ABBREVIATIONS

CI= conventional irrigation

CNI = conventional needle irrigation

EA= EndoActivator

EDTA = ethylenediaminetetraacetic acid

E.Faecalis = Enterococcus faecalis

Er-Flat = Er:YAG laser with a plain fiber tip inside the canal

Er-PIPS = Er:YAG laser with a conical tip held at the canal entrance

Er:YAG = Erbium:yttrium-aluminum-garnet

FESEM = Field Emission Scanning Electron Microscopy

G1 = group 1

G2 = group 2

G3 = group 3

G4 = group 4

G5 = group 5

G6 = group 6

G7 = group 7

G8 = group 8

G9 = group 9

ISO = International Organization for Standardization

LAI = Laser assisted irrigation

MDI = manual-dynamic irrigation (with a gutta percha)

NaOCl = sodium hypochlorite

Nd:YAG = neodymium-doped yttrium aluminum garnet

Nd:YAP = neodymium-doped yttrium aluminium perovskite

NS = normal saline

PDT = photodynamic therapy

PUI = passive ultrasonic irrigation

RCP = root canal preparation

SNI =Single needle irrigation

SWEEPS = Shock Wave Enhanced Emission Photoacoustic Streaming

UAI = ultrasonically activated irrigation

.

1. INTRODUCTION

Root canal treatment goals are complete or critical elimination of microbial content and prevention of reinfection (1).

Root canal preparation through instrumentation produces the smear layer, made of organic and mineral debris, which is considered as a negative factor (2). Indeed, it prevents irrigation solutions, medicaments, and root canal sealers from penetrating into dentinal tubules (3). The main used method for its removal is chemical irrigation solution and sodium hypochlorite (NaOCl), in a range of concentration from 0.5% to 5.25%, is the most used irrigant for root canal treatment (2,4). NaOCl has an excellent tissue dissolving capacity and microbicidal activity, but it has a limited effect on the dissolution of the smear layer (2). Acid solutions have been recommended for smear layer removing, including sodium salt of ethylenediaminetetraacetic acid (EDTA), most active at a concentration of 15%-17% and pH of 7-8; citric acid solutions, used at concentrations of 10%, 25%, and 50%; and orthophosphoric acid at concentrations of 10%, 32%, and 37% (2). These irrigation solutions significantly improve the cleaning ability of root canals. However, the combination of both NaOCl and EDTA does not completely remove the smear layer (2).

Root canal irrigation is traditionally performed using a syringe-needle combination. However, the irrigation solution penetration in the apical third and beyond the main canal is limited (5). Thus, irrigation activation is suggested to increase its efficacy and improve root canal cleanliness (6).

In the past decades, passive ultrasonic irrigation (PUI) has been widely used for root canal irrigation. Combined with NaOCl, PUI could'nt only effectively remove the smear layer inside infected root canals but also significantly improve the cleaning of biofilm-infected dentine (7). For PUI, however, the apical third of a root canal should be enlarged to at least an International Organization for Standardization (ISO) size of 30–40 to allow needle placement to within 1–2mm of the apical seat (7), which might limit its application.

In the past few years, laser technologies have been used for irrigation solution activation. It generates explosive vapor bubbles with a secondary cavitation impact and provides influential removal of the debris and smear layer from the complex root canal systems anatomy (8). Photon-induced photoacoustic streaming (PIPS) is a novel laser agitation technique used with an erbium:yttrium-aluminum-garnet (Er:YAG) laser. Contrary to other agitation techniques, the tip is only placed into the canal orifice without moving into the root canal. It utilizes low-energy levels and short microsecond pulse rates (50 μs) to produce the highest-power spikes (8). The profound photoacoustic shock wave allows the three-dimensional movement of the irrigation solutions. Compared to conventional irrigation, it provides significantly better removal of the smear layer, debris, medicaments, or bacteria from the root canal walls, and higher bond strength values for the root canal sealer and resin cement (8). In 2017 a SWEEPS (Shock Wave Enhanced Emission Photoacoustic Streaming) technique has been developed in order to improve the efficacy of LAI (Laser assisted irrigation) in narrow endodontic cavities (9).The SWEEPS dual-pulse modality is based on the generation of series of bubbles produced by synchronized ultrashort laser pulses of low energy (20 mJ) delivered in the liquid, timed to appear such that secondary bubble leads to a collapse of existing bubble, amplifying pressure waves in the liquid and causing powerful photodynamic streaming (10). It seems that LAI can also be obtained using near infrared diode lasers. This is of particular interest because they are cheaper and more compact than erbium laser systems (5).

This integrative systematic review pretends to evaluate the efficacity of laser assisted irrigation in disinfecting and cleaning root canals against traditional irrigation and other activation methods.

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

2. OBJECTIVES

Main Goal:

- The aim of this study is to evaluate if an irrigation solution activated with a laser is more effective than traditional irrigation methods in disinfecting the root canal system, removing debris and the smear layer.

Secondary Goal:

- Evaluate the promotion of a better penetration of both irrigation solution and sealing materials in dentinal tubules.

Null hypothesis:

- The H0 hypothesis followed in this study was "Activate an irrigation solution with a laser is not more effective in root canal disinfection than conventional irrigation without activation or activated by sonic or ultrasonic activation devices"

3. MATERIALS AND METHODS

3.1. Study type

This study is an integrative systematic review.

3.2. *PICOS*

The qualification criteria were incorporated using the PICOS framework (population, intervention, comparison, outcomes, and study design). In the PubMed and ScienceDirect databases, articles from 2014 to 2024 were searched using the keywords: "laser", "root", "canal", "irrigants".

Table 1 : PICOS Strategy

Population	**Endodontically treatable tooth.**
Intervention	Root canal irrigation.
Comparison	No activation, Ultrasonic activation, Laser activation.
Outcome	Root canal cleaning efficiency, smear layer removal.
Study design	In-vitro study Ex-vivo study

3.3. Inclusion and exclusion criteria:

Inclusion eligibility criteria were as follows:

i) Articles published from 2014 to February 2024;

ii) Language : English,

iii) In vivo, in vitro and ex-vivo study;

iv) Randomized controlled clinical trials, prospective, randomized, and controlled investigations, case series, clinical case reports, observational studies, cohort studies, prospective studies

Exclusion eligibility criteria were as follows

i) Systematic review and meta-analysis.

ii) Thesis and dissertation;

iii) Articles prior to 2014;

iv) Articles which title and/or resume do not fit the theme;

v) Articles without an abstract

3.4. Search strategy and keywords.

3.4.1. Methodology

A Literature search was performed in the following databases, PubMed https://pubmed.ncbi.nlm.nih.gov, and ScienceDirect https://www.sciencedirect.com, using the following keywords ; laser, root, canal, irrigants.

The search was carried out between April 2013 and February 2024, using keywords and MeSH terms related to the topic in question. The different Mesh terms were only combined using the "AND" future, and "OR" was not used in our search.

Table 2 : Results obtained from the search.

DATA BASE	SEARCH STRATEGY	IDENTIFICATED ARTICLES
PUBMED	(("Lasers"[Mesh]) AND "Root Canal Irrigants"[Mesh]) NOT "Systematic Review" [Publication Type]	122
SCIENCEDIRECT	(("Lasers"[Mesh]) AND "Root Canal Irrigants"[Mesh]) NOT "Systematic Review" [Publication Type]	91
TOTAL		213

3.4.2. Data extraction

After conducting a detailed search using keywords and MeSH terms, we identified 213 articles. Out of this total, 2 were discarded for being duplicates. To check the adherence of the remaining 211 studies to the inclusion criteria, we analysed the titles and abstracts of the selected articles. In this process, we eliminated 176 studies for not meeting the necessary requirements for our research, including the use of diode or Er:YAG laser in root canal irrigation activation techniques. Next, we conducted a full analysis of 35 articles, with special attention to the "materials and methods" and "results" sections, to determine their relevance. This step resulted in the exclusion of an additional 20 studies, culminating in the final selection of 15 studies for our review. The data from these studies were then collected and systematized in a table.

3.4.3. Data collection process

The selected articles were analysed in detail to extract specific information, including Title, Authors and Date, Objectives, Type of Study, Sample, Intervention, and Results. After collecting this information, the data were organized and recorded in Table 3, located in the results chapter.

4. RESULTS

4.1. Litterature search Fluxogram (PRISMA)

After selection, 15 articles were included in the present review. The article selection process is illustrated in the flowchart diagram PRISMA.

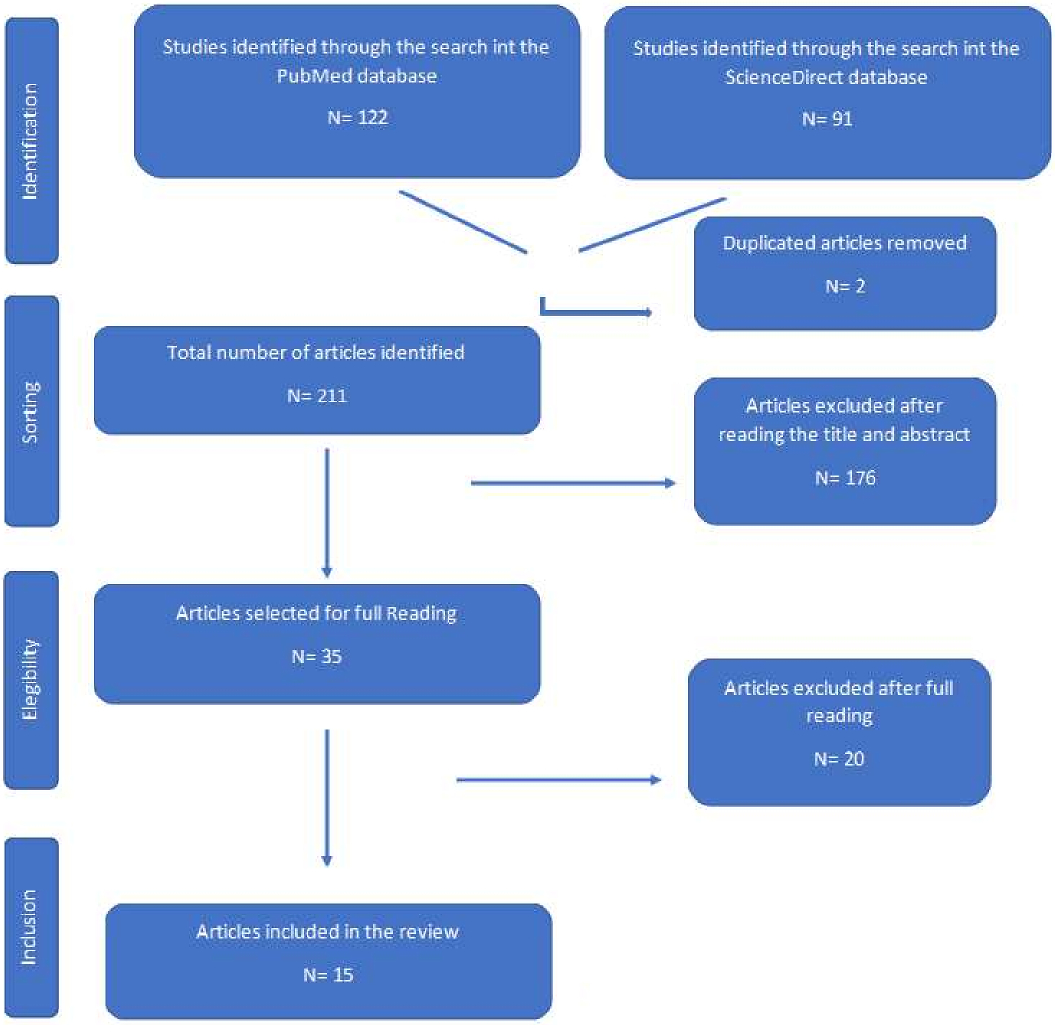

Figure 1 - Flowchart of the research strategies

4.2. Study distribution

The 15 studies are distributed as follows: 12 in-vitro study, 3 ex-vivo study.

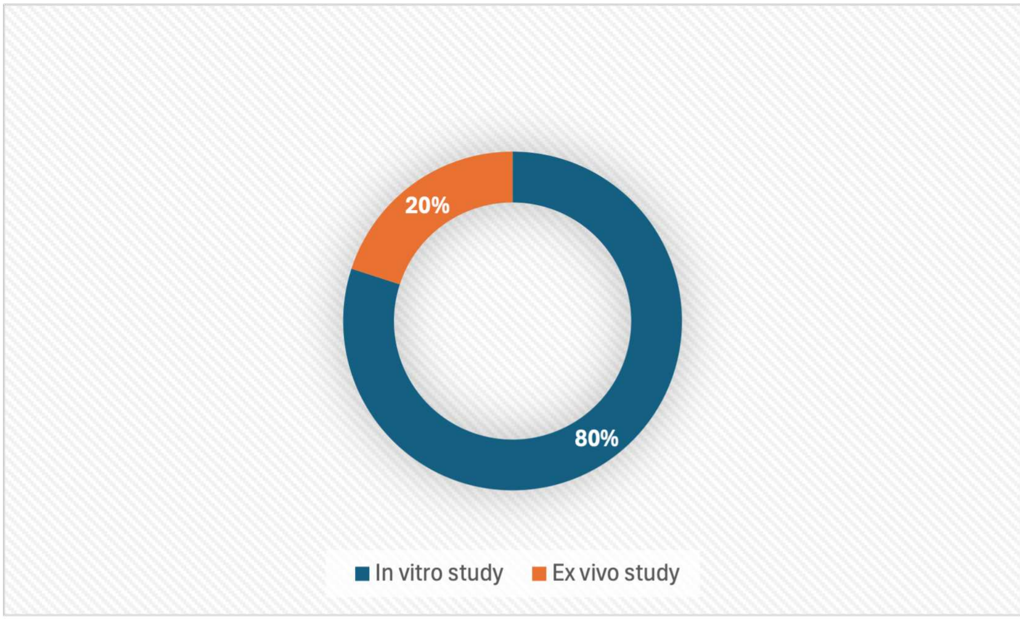

Figure 2 - Classification by types of studies.

Table 3 : Relevant data collected from the selected studies

Title, author and year	Goals	Study type	Sample and Intervention	Results	Conclusion
Efficacy of Laser-Based Irrigant Activation Methods in Removing Debris from Simulated Root Canal Irregularities. Deleu et al. 2015.	The purpose of this in vitro study was to compare the efficacy of different irrigant activation methods in removing debris from simulated root canal irregularities.	In-vitro study	25 straight human canine roots G1: CNI G2: MDI G3: PUI G4: Er-flat G5: Er-PIPS G6: diode laser	The erbium laser with the flat fiber tip removed significantly more debris than the diode laser (P = 0.007), the MDI (P = 0.02), and the erbium laser using the PIPS tip (P = 0.004), but the amount of debris was not statistically different from that found in the PUI group.	The Er:YAG with plain fiber tip was more efficient than MDI, CI, diode, and Er:YAG laser with PIPS tip in removing debris from simulated root canal irregularities.
The Effectiveness of the Erbium:Yttrium Aluminum Garnet PIPS Technique in Comparison to Different Chemical Solutions in Removing the Endodontic Smear Layer-an in Vitro Profilometric Study. Nasher, et al. 2016	This study evaluated the degree of endodontic smear layer removal using the Er:YAG PIPS technique (2.94 μm) in comparison with different irrigants	In-vitro study	64 single-rooted teeth G1 (positive control): 3 % NaOCl + 20 % EDTA. G2 (negative control): 0.9 % NaOCl G3: 3 % NaOCl G4: 20 % EDTA G5: 3 % NaOCl +.20 % EDTA + laser. G6: 0.9 % NaOCl + laser. G7: 3 % NaOCl + laser. G8: 20 % EDTA + laser	No significant difference was observed between the groups treated only with irrigants and those treated with Er:YAG PIPS and the same irrigants ($p \geq 0.0018$).	The Er:YAG PIPS technique did not show any improved results in removing the smear layer when compared to the irrigants alone. Moreover, the open dentinal tubules in some groups were a result of the chelating action of 20 % EDTA.

Comparison of Smear Layer Removal Ability of QMix with Different Activation Techniques. Arslan, et al. 2016	Evaluate the effectiveness of an irrigation solution (QMix) on the smear layer using different irrigation activation techniques	In-vitro study	64 extracted single-rooted human teeth. Experimental groups (*n* = 8/group) G1: QMix + CSI G2: QMix + EA G3: QMix + PIPS G4: QMix + Er:YAG laser (endodontic fiber tip) Negative control groups (*n* = 8/group): G5: DW + CSI G6: DW + EA G7: DW + PIPS activation G8: DW + Er:YAG laser (endodontic fiber tip)	The QMix + Er:YAG group removed the smear layer more effectively than the nonactivated QMix group in the apical third ($P < .05$). The QMix + PIPS group showed a significantly better effect than the QMix group in the coronal third ($P < .05$).	The EA and Er:YAG laser enhanced the smear layer removal ability of QMix in the apical thirds of the canals. QMix removed more smear layer in the coronal thirds when activated with the PIPS technique.
Bactericidal effect of Er:YAG laser combined with sodium hypochlorite irrigation against Enterococcus faecalis deep inside dentinal tubules in experimentally infected root canals. Cheng et al. 2016	Evaluated the bactericidal effect of Er:YAG laser radiation combined with NaOCl irrigation in the treatment of Enterococcus faecalis deep inside dentinal tubules.	Ex-vivo study	155 caries-free, intact, single-rooted, extracted for orthodontic treatment, permanent human teeth with straight root canals G1: untreated (n=10) G2: normal saline as negative control (n=15) G3: NaOCl as positive control (n=15) n=15/group for G4 to G9: Er:YAG + NaOCl G4: 0.3W, 20s, 15Hz G5: 0.3W, 30s, 15Hz G6: 0.5W, 20s, 25Hz G7: 0.5W, 30s, 25Hz G8: 1W, 20s, 50Hz G9: 1W, 30s, 50Hz	Er:YAG laser combined with NaOCl disinfected the dentinal tubules from 200 to over 500 μm depth as irradiation power and time increased. It killed significantly more bacteria than both the negative control group at each level tested and the positive control group at 300, 400 and 500 μm inside the dentinal tubules. Only the groups treated with 0.5 and 1.0W for 30s exhibited no bacterial growth (100 % loss of bacteria) at 300, 400 and 500 μm inside dentinal tubules.	Of the two groups in which no bacteria were detected at all tested depths, Er:YAG laser irradiation at 0.5W for 30s combined with NaOCl irrigation was preferable because of the lower emission power and shorter irradiation time and may serve as a new option for effective root canal disinfection.

Effect of photon-initiated photoacoustic streaming, passive ultrasonic, and sonic irrigation techniques on dentinal tubule penetration of irrigation solution: a confocal microscopic study. Akcay et al, 2017	Evaluate the efficacy of different irrigation techniques including laser-activated irrigation on the final irrigation solution penetration into dentinal tubules by using a laser scanning confocal microscope	In-vitro study	65 extracted single-rooted human mandibular premolars G1: Conventional irrigation: G2: Er:YAG-PIPS tip G3: Er:YAG-Preciso tip G4: Sonic irrigation G5: PUI n = 13/ group	Both Er:YAG laser activations exhibited a significantly higher penetration area than the other groups ($P < 0.05$). Statistically significant differences were also found between each root canal third (coronal > middle > apical) ($P < 0.001$).	The results from the present study support the use of Er:YAG laser activation (Preciso/PIPS) to improve the effectiveness of the final irrigation procedure by increasing the irrigant penetration area into the dentinal tubules.

Effect of Different Agitation Techniques on the Penetration of Irrigant and Sealer into Dentinal Tubules. Gu et al. 2017	The aim of this study was to compare the effectiveness of five intracanal agitation techniques on the penetration of irrigant and sealer into dentinal tubules.	In-vitro study	60 human maxillary premolars with single straight canals G1: CNI as control group G2: Sonic G3: Ultrasonic G4: V-Clean™ endodontic agitation system G5: 1.34 μm Nd:YAP laser at 280 mJ at a 10 Hz n=12/group	Laser agitation attained the most irrigant and sealer penetration depth and penetration percentage ($p < 0.05$). Patterns of irrigant and sealer penetration correlated significantly for all agitation techniques ($p < 0.001$).	Nd:YAP laser was superior to other agitation techniques in dentinal tubule penetration of irrigant and sealer at one or more sectioned levels from the apex.

A Comparative Evaluation of Smear Layer Removal by Using Different Er:YAG Lasers Parameters: An İn-Vitro Scanning Electron Microscopic Study. Gorus et al. 2018	Investigate the effect of irrigation activation methods using different laser parameters on microhardness and push-out bonding strength of root canal dentin and compares the efficacy of different laser parameters in smear layer removal using the scanning electron microscopic image analysis.	In-vitro study	60 newly extracted human teeth G1: Er:YAG laser with 0.6 W, 15 Hz, and 40 mJ (n=20) G2: Er:YAG laser with 0.3 W, 15 Hz, and 20 mJ (n=20) G3: CNI as control group (n=20)	As a result of the push-out bonding strength test performed on the coronal and apex regions of laser treated and untreated groups, the values of the coronal region were found to be higher than the apex region, and it was found that the bonding strength of the coronal part of the laser group was increased ($P < 0.05$). Analysis results of the laser group showed relatively clean and rough tooth surfaces and low smear layer amount compared to the control group	According to this study the laser group increases the bonding strength without a negative change in microhardness. In this study the further research is needed on this subject.
Characteristics of Bubble Oscillations During Laser-Activated Irrigation of Root Canals and Method of Improvement. Lukač, et al. 2020	Show that the irrigation efficacy, as measured by the induced pressure within the canal, is related to the double pulse delay, with the maximal pressure generated at an optimal delay. The second aim is to find a method of determining the optimal delay for different cavity dimensions and/or laser parameters.	In-vitro study	Transparent models of root canals Er:YAG laser ($\lambda = 2.94$ μm, pulse duration $t_p = 25$ or 50 ms, and pulse energies up to $E_L = 40$ mJ) was used with a combination of cylindrical and conical fiber-tip geometries (diameters 400 and 600 μm)	A pressure amplification of more than 1.5 times occurs if the laser pulse delay approximately coincides with the bubble oscillation time. Correlations between normalized oscillation time and canal diameter for a wide range of laser pulse energies ($R2 = 0.96$) and between the average pressure within the canal and the bubble oscillation periods ($R2 = 0.90$) were found. A relationship between the bubble oscillation time and the diameter of the treated cavity was found depending on the bubble oscillation time in an infinite fluid reservoir.	The bubble oscillation time within a constrained volume can be determined based on the known oscillation time in infinite space, which offers a fast and simple solution for optimization of the laser parameters. These findings enable determination of optimal conditions for shock wave generation, and improvement of root canal irrigation at the same dose of laser energy input, leading to improved treatment efficacy and safety.

A Comparative Evaluation of the Efficacy of Erbium: Yttrium-Aluminum-Garnet and Diode Lasers in Smear Layer Removal and Dentin Permeability of Root Canal after Biomechanical Preparation - A Scanning Electron Microscopy Study. Dhawan et al. 2020	The aim of this study is to compare the efficacy of erbium: yttrium-aluminum-garnet (Er:YAG) and diode laser irradiation in smear layer removal and dentin permeability after biomechanical preparation using scanning electron microscopic investigation	In-vitro study	30 sound single-rooted human teeth G1: CNI as control group with 17% EDTA (n=10) G2: diode laser irradiation (n=10) G3: Er:YAG laser irradiation (n=10)	Smear layer removal efficacy of Er:YAG laser was more at coronal, middle, and apical third when compared to Group I and Group II. Debris removal score of Er:YAG laser was better than diode laser and (17% EDTA) .	Er:YAG laser-activated RCP was comparatively efficient in cleaning the smear layer and dentinal tubules opening.
FESEM Evaluation of Smear Layer Removal from Conservatively Shaped Canals: Laser Activated Irrigation (PIPS and SWEEPS) Compared to Sonic and Passive Ultrasonic Activation-an Ex Vivo Study Mancini et al. 2021	The aim of this study was to assess the effectiveness of different irrigants activation methods in removing the smear layer at 1, 3, 5 and 8 mm from the apex from conservatively shaped canals.	In-vitro study	85 human mandibular premolars G1: CNI as control group (n=5) G2: EA (n=20) G3: PUI (n=20) G4: PIPS (n= 20) G5: SWEEPS (n=20)	At 1 mm from the apex, only PIPS and SWEEPS performed better than the control group. At 3, 5 and 8 mm every activation technique showed statistically significant reduction of smear layer when compared to the control group. PIPS and SWEEPS obtained better cleanliness result compared to EA, while only PIPS was superior to PUI in terms of cleanliness.	PIPS and SWEEPS showed the best results in conservative canal preparations. Nowadays, contemporary rotary instruments allow fast and minimally invasive shaping of the endodontic space. In this scenario irrigants' activation may be regarded as a mandatory step to a favourable clinical outcome.

Laser Activated Irrigation with SWEEPS Modality Reduces Concentration of Sodium Hypochlorite in Root Canal Irrigation Lei et al. 2022	Compare the effects of different concentrations of sodium hypochlorite (NaOCl) combined with SWEEPS root canal irrigation on the removal of Enterococcus faecalis in infected bovine root canals.	In-vitro study	48 bovine root canals infected with E.Faecalis (8 samples /group) G1: NS+CNI G2: NS+SWEEPS G3: 0.5% NaOCl+SWEEPS, G4: 1% NaOCl+SWEEPS G5: 2% NaOCl+SWEEPS G6: 5.25% NaOCl+SWEEPS	After root canal irrigation, the viable count in each group was significantly reduced ($P < 0.05$). The bacterial reduction in NS+CI and NS+SWEEPS groups was significantly lower than that in other groups ($P < 0.05$). Thus, groups with NaOCl+SWEEPS showed better bacterial reduction.	This study showed that SWEEPS used for root canal irrigation can enhance the effect of low-concentration NaOCl while ensuring the antimicrobial effect.
Effect of Low-Power Diode Laser on Infected Root Canals. Alves et al, 2022	This study evaluated the effect of photodynamic therapy (PDT) on infected root canals.	In-vitro study	21 extracted single-rooted human teeth with intact cement G1 and G2: RCP + 2.5% NaOCl + 17% EDTA + PDT G1 with rotatory and G2 with hand files. G3 and G4: RCP + 2.5% NaOCl + 17% EDTA G3 with rotatory and G4 with hand files. G5: 2.5% NaOCl + 17% EDTA + PDT (No RCP) G6: S1 as Negative control G7: S1 as Positive control	Bacteria were found in all experimental groups' microbiological samples (S1, S2 and S3). After PDT (S3) in G1 and G2, there was an additional reduction in optical density of the culture medium, respectively ($p>0.05$).	PDT after root canal preparation using the rotary system or manually, associated with 2.5% NaOCl, was not able to completely eliminate *E. faecalis* mature biofilm present in the root canal.

Novel laser activated photoacoustic streaming for removing pulp remnants from round root canals after single file reciprocating instrumentation Bago et al. 2022	Evaluated the efficacy of a new laser-assisted irrigation system, the shock wave enhanced emission photo-acoustic streaming (SWEEPS) technique in removing pulp tissue from single-rooted premolars.	Ex-vivo study	40 extracted mandibular premolars with round root canals 4 experimental groups (n = 8/group): G1. SWEEPS G2. UAI G3. CNI G4. Single SWEEPS® without previous instrumentation G5: Control group (n = 8): untreated	Significant differences were observed between the control group and the experimental groups ($p<0.05$). In the middle third, the UIA and SWEEPS showed similar efficacy ($p = 0.171$), superior to CI and SWEEPS without instrumentation ($p<0.05$). In the apical third, SWEEPS was the most efficient ($p = 0.002$), and UIA and CI showed no difference ($p = 0.643$).	SWEEPS was superior to UIA and CI in removing RPT in the apical region of round canals after single instrument root canal preparation; SWEEPS without instrumentation was inefficient in removing pulp tissue.
Root Canal Cleaning in Roots with Complex Canals Using Agitated Irrigation Fluids allinari Kumar, et al. 2023	The aim of this laboratory study was to assess the effectiveness of laser agitation of sodium hypochlorite in removing multispecies biofilms grown in the mesial root of the permanent first molars	In-vitro study	Five agitation groups (N = 12 roots for each) G1: 940 nm Diode laser agitation G2: 1064 nm Nd:YAG laser agitation G3: 2940 nm Er:YAG laser G4: PUI as positive control G5: CNI as negative control	No significant differences in canal wall cleanliness were found between the treatment groups, at any of the three levels in the root. None of the tested methods were effective in completely eradicating biofilm from the most confined regions of the root canal system	The major challenge appears to be cleaning the isthmuses. There was a positive correlation between canal cleaning and isthmus cleaning, suggesting that increased effectiveness in cleaning root canal walls is associated with more effective isthmus cleaning. Wider and narrow isthmuses were cleaned better than long and narrow isthmuses.

Investigation of the Effectiveness of Sonic, Ultrasonic and New Laser-Assisted Irrigation Activation Methods on Smear Removal and Tubular Penetration. Uslu et al, 2023	Examine the effectiveness of different irrigation activation methods on smear layer removal and tubular penetration.	Ex-vivo study	105 distal roots of mandibular molar teeth. Negative control group: n=5 Tubular penetration examination 5 group of n=10 smear removal efficiency 5 group of n=10 CNI, sonic irrigation (EDDY), PUI, PIPS and SWEEPS were used in those groups.	At the apical level: cleanest canal with PIPS and SWEEPS. In the middle third: no difference in smear removal efficiencies except for the CNI $p > 0.05$). Greater penetration depth and percentage with PIPS ($p < 0.05$). PIPS and SWEEPS techniques showed lowest and similar smear scores in the apical area where access and effectiveness of the irrigation solution are difficult.	Irradiation of the Er:YAG laser with a PIPS or SWEEPS tip further removed the smear layer and showed a significant increase in penetration depth of the root canal sealer.

5. DISCUSSION

5.1. Debris and Smear Layer removal:

A majority of authors claims that devices which activate the irrigation solution promote cleaner root canal wall compared to non-activated irrigation (1,3,5,6,8,10,11). Thus, we can expect that activating the irrigation solution through laser might produce the same effect. According to Deleu et al. (5), irrigation solution activated with a 980 nm diode laser removed significantly more debris than conventional syringe irrigation. They found the same result for Er:YAG laser with both conventional fiber tip and PIPS tip (5). Arslan et al. (6) demonstrated that the Er:YAG laser, used with a plain fiber or PIPS tip, enhanced the removal of smear layer and debris in both the coronal and apical thirds of the root canal. However, in the PIPS tip group, this effect was statistically significant only in the coronal third (6). Gorus et al. (12) demonstrated that the smear layer and debris present on root canal walls negatively affected bonding strength. Additionally, they found that a group treated with Er:YAG laser had higher bonding strength compared to a group treated with CNI (12). Thus, this might also confirm that Er:YAG laser is more effective than CNI in debris and smear layer removal. Dhawan et al. (2) explained that comparing to CNI, a better smear layer and debris removal at the coronal, middle, and apical third was shown while irrigation solution was activated with both diode laser and Er:YAG laser. Mancini et al. (10) confirmed that the Er:YAG laser using a PIPS tip performed better in smear layer removal than CNI, even at the apical level. Finally, Uslu et al. (3) found no differences between CNI and Er:PIPS/ Er:SWEEPS at coronal level. They concluded a better smear layer removal for both Er:PIPS and Er:SWEEPS than conventional irrigation at both middle and apical third (3).

Contrary to previous authors (2,3,5,6,12), Nasher et al. (4) found that Er:YAG laser activating various concentration of NaOCl (0.9 to 3%) or 20% EDTA, was not more effective than syringe irrigation.

Most of these authors (2,3,5,6,12) concluded that the activation of the irrigation solution through Laser technologies was more effective than CNI in debris and smear layer removal. According to Nasher et al. (4) the ultra-low power settings used could be the reason for their different results.

Then, comparing the irrigation solution activation with a laser against other activation methods might be interesting.

According to Deleu et al. (5) findings, there were no significant differences between a PUI group and an Er:YAG laser group in debris removal. Nasher et al. (4) found that various concentrations of NaOCl (0.9 to 3%) or 20% EDTA activated with an Er:YAG laser was not more effective than other activation methods such as PUI. Arslan et al. (6) found a significantly better smear layer removal for EA than Er:YAG laser with conventional tip in the middle third, but no significant difference was evidence with Er:PIPS. On the other hand, Mancini et al. (10) demonstrated that Er:PIPS was significantly better than EA and PUI at 1, 3, 5 and 8 mm from the apex. Interestingly, they discovered that Er:PIPS was effective in removing smear layer by activating a saline solution which alone could not remove smear layer (10). They also discovered that Er:SWEEPS removed more smear layer than CNI and EA, but no difference was found with PUI treated group (10). According to Uslu et al. (3), Er:PIPS and Er:SWEEPS showed the lower smear scores compared to PUI and EDDY, in the apical region where irrigation is more difficult due to complex anatomy and difficult access.

As discussed above, authors don't seem to agree on the results. Therefore, various explanation can be provided. Arslan et al. (6) explained that *"The mechanism for the laser activation of irrigating solutions originates from the absorption of laser energy; formation of vapor bubbles; collapse of the bubbles; acoustic streaming; and, finally, cavitation."* (p1282). Furthermore, Deleu et al. (5) also explained it by the size of the tip. Thus, a smaller fiber tip and high pulse of energy might enhance the cavitation effect of the laser (5). Indeed, Deleu et al. (5) and Nasher et al. (4) used ultra-low energy levels compared to other authors (3,10). Another viable explanation is the influence of the apical size. Mancini et al. (10) explained that an ISO 40 used by Nasher et al. (4) may have facilitated the action of EA and PUI. Thus, by using an ISO 25 as an apical size, laser performed better than those previous methods (10). This is confirmed by Uslu et al. (3) who explained that their results might be due to their use of a smaller apical size of ISO 30. In fact, PUI and sonic devices are more effective at an ISO 40 apical diameter. This result may show the particular interest of laser technologies in more complex canal, and/or in more conservative preparation.

Finally, another way to evaluate the efficacy of the laser in activating the irrigation solution is to compare different laser, or different laser protocols. Deleu et al. (5) concluded that the Er:YAG laser with a conventional fiber tip was significantly better than the diode laser and the PIPS Er:YAG laser for debris removal. According to Arslan et al. (6) the Er:YAG laser with plain fiber tip is better than PIPS tip in apical region. Dhawan et al. (2) showed that Er:YAG laser was better for smear layer and debris removal than diode laser, which may confirm the results of Deleu et al. (5).

Mancini et al. (10) did not found statistical differences between Er:SWEEPS and Er:YAG in removing smear layer. Finally, according to Uslu et al. (3), PIPS and SWEEPS techniques showed significantly similar smear layer elimination in the apical region, where according to them (3) *"access and effectiveness of the irrigation solution is difficult."* (p7).

Thus, its seem that the Er:YAG laser is more effective than diode laser. Indeed, Deleu et al. (5) explained that the *"absorption of diode laser radiation in aqueous solutions is far less than that of erbium lasers"* (p835) and Arslan et al. (6) confirmed that Er:YAG laser has the highest absorption in water. Furthermore, it is not possible to use diode laser at high power, because it could result in dentin burning (5). In fact, at high power the radiation could not be absorbed by the water and the tip could enter in contact with the dentin and burn it (5). Deleu et al. (5) referred that a study model had to be replaced due to carbonization of the root canal wall. In consequence, they concluded that with a limited effect at high output power, and potential damage due to high local temperatures, the 980 nm diode laser could not be efficient in activating an irrigation solution (5).

For the Er:YAG laser, it seems that no clear tendences can be established. According to Deleu et al (5), the PIPS tip produces more lateral emission of energy than plain fiber tip by offering a very short pulse which create a photoacoustic shockwave in the irrigation solution and improves its efficacy. However, in practice the ultra-low energy levels used for the PIPS tip could explain their findings (5). Nasher et al. (4) also explained that the different power settings could be the reason for such different results. Furthermore, the irrigation method, which allowed a fluid-free canal after 4s of activation is also limiting the effect of the PIPS tip and such a problem was not found by using the plain fiber tip according to Deleu et al. (5). Moreover, Arslan et al. (6) suggested that the PIPS method induces significant turbulence in the fluids within the canals, yet the laser tip's ability to penetrate remains a crucial factor for the removal of the apical smear layer. They have also found that PIPS tip produces minimal thermal effect and allows minimally invasive preparation (6).

In conclusion, further studies will be needed to have a clear view on the different laser efficacities. It will be interesting to compare them using different power setting at different levels in the root canal.

5.2. Irrigant and sealer penetration in dentinal tubules:

It was previously showed that NaOCl needs direct contact to produce its bactericidal effect (7).

According to Cheng et al. (7) *E. faecalis* can penetrate dentinal tubules to depths exceeding 1350 µm, but in majority, *E. faecalis* is present at 400 µm inside dentinal tubules, with only few invading beyond 500 µm. Thus, ensuring disinfection of the dentinal tubules to a depth of 500 µm may lead to an ideal outcome in endodontic therapy (7). Cheng et al. (7) found that about 99.98% of *E. faecalis* was eliminated of the root canal walls while performing a CNI, and only 91.99% of *E. faecalis* were eliminated at 500 µm. According to Cheng et al. (7), the activation of irrigation solution with an Er:YAG laser eliminated significantly more bacteria in deep dentine than the irrigation through conventional syringe-needle combination. Moreover, Akcay et al. (8) showed that the activation of the irrigation solution through an Er:YAG and Nd:YAG laser promoted a significantly higher penetration of the irrigation solution in dentinal tubules than conventional needle irrigation. Gu et al. (1) confirmed that Nd:YAP laser permitted both irrigation solution and sealing material a better penetration into dentinal tubules. Furthermore, Bago et al. (11) demonstrated that the Er:SWEEPS laser also allowed a better penetration of the irrigation solution in dentinal tubules.

Hence, authors seem to agree on the truth that activation of the irrigation solution with laser technologies is more effective than conventional needle irrigation for disinfecting root canals in depth of dentinal tubules.

Since these results are not surprising, comparing laser technologies against other irrigation solution activation devices might be interesting. According to Cheng et al. (7), the bactericidal effect of Er:YAG laser in combination with NaOCl on the root canal surface was equivalent to employing PUI alongside NaOCl. However, at 500 µm inside dentinal tubules, Er:YAG laser showed better results than PUI (6).

Contrary to Cheng et al. (7), Akcay et al. (8) found that Er:YAG laser with preciso tips or PIPS tip had a significantly better dentinal tubules penetration than PUI and other conventional agitations techniques, in all third of the root canal. The PIPS technique relies on photo-acoustic and photo-mechanical actions without the need to reach the root apex (8), contrary to PUI methods, which requires an ISO size of at least 30-40 to reach the apical seat (7). Furthermore, by being placed at the entry of the root canal, Er:YAG laser using PIPS tip is potentially effective for treating both straight and curved root canals (7).

The apical region has always been the most difficult part to disinfect (8). According to Akcay et al. (8), in the apical region, only the Er:YAG laser activation of the irrigation solution - here with a Preciso or PIPS tip – performed better than the control group in promoting a better penetration of irrigation solution in dentinal tubules. By utilizing a Nd:YAP laser, Gu et al. (1) concluded that it performed better than sonic and ultrasonic activation devices, in promoting the penetration of irrigation solution and sealers into dentinal tubules. Bago et al (11). evidenced that an Er:YAG laser using SWEEPS protocol also promoted a deeper penetration of irrigation solution into dentinal tubules, compared to UAI. Uslu et al (3) confirmed that activating the irrigation solution with both PIPS and SWEEP Er:YAG laser permitted a better tubular penetration of irrigation solution comparing to sonic and ultrasonic activation techniques.

In facts, PUI and EDDY affected positively the penetration of irrigation solution into dentinal tubules at a coronal level, but at both middle and apical third, they were not more effective than CNI (3). Thus, it seems that different laser technologies are better than other irrigation solution activation techniques in promoting the penetration of irrigation solution in depth into dentinal tubules. However, further studies are needed to evidence the effect of laser technologies on the penetration of sealers in those tubules.

Not much literature was available to have a clear comparison between different laser or different laser settings. However, Cheng et al. (7) experimented with the Er:YAG laser with various energy pulse and power. They only found 100% of bacterial reduction at 500 μm using two settings: 0.5 for 30 s and 1.0 W for 30 s. Thus, by using Er:YAG laser to activate the irrigation solution, these settings may be ideal to disinfect the root canal in depth.

5.3. Root canal disinfection:

According to Lei et al. (13), while activating different concentrations of NaOCl (0.5%, 1.0%, 2.0%, and 5.25%), SWEEPS showed a better bacterial reduction than conventional irrigation. This may suggest that SWEEPS improve the bactericidal effect of NaOCl event at low concentration and in consequences reduce the risk of iatrogenic damage due to high concentration of NaOCl (13). Their findings are supported by the result of Bago et al. (11), who concluded that activated with SWEEPS, irrigation solution was more effective than conventional needle irrigation in removing remaining pulp tissue from root canal. Furthermore, Alves et al. (14) found more bacterial reduction in a group which irrigation solution was activated with diode laser than a group treated conventionally.

According to Bago et al. (11), by activating an irrigation solution, Er:YAG laser in SWEEPS mode was more effective than UAI and was the only group that completely eliminated remaining pulp tissue irrigation after single-file reciprocating instrumentation. Kumar et al. (15) found that an irrigation solution activated respectively with Er:YAG, Nd:YAG, and diode laser was not more effective than conventional needle irrigation and passive ultrasonic irrigation in removing biofilm from molars. These results may differ from previous authors due to the nature of the tooth used (11). In fact, contrary to Bago et al. (11) which used single-rooted premolars with larger canals, Kumar et al. (15) used the mesial root of first molar. Thus, we can conclude that an irrigation solution activated through laser is probably better than conventional needle irrigation and other agitation techniques in disinfecting root canals.

The superiority of laser systems in terms of disinfection might ask if root canal instrumentation is needed. Bago et al. (11) and Alves et al. (14) activated root canal irrigation without previous instrumentation. According to Bago et al. (11), SWEEPS activating 3 % NaOCl could not completely dissolve and eliminate remaining pulp tissue from root canals, leaving 57 % after 180 s activation. Therefore, SWEEPS without instrumentation was less effective than both UAI and SWEEPS with instrumentation. The results of Alves et al. (14) confirmed that without instrumentation, groups treated with diode laser showed less bacterial reduction than groups previously instrumented. Bago et al. (11) explained that Er:SWEEPS laser could only achieve its plain potential combined with root canal preparation.

Thus, according to Alves et al. (14) laser system is considered as a complementary protocol to root canal preparation and should not be used without previous instrumentation.

Finally, according to Lukač et al. (9) in root canal treatment, the cavitation effect produces by the laser is not determined by the diameter, curvature or complex anatomy, but by dimension of the access cavity which surrounds the fiber tip.

Therefore, further studies on laser systems with minimal root canal preparation might be interesting for the future of endodontics.

5.4. Limitations:

Our study only included in-vitro and ex-vivo studies, without including in-vivo studies which may be closer to clinical reality. Furthermore, most of studies used single rooted canal which may be easier to irrigate than posterior tooth with more complex anatomy.

Further studies are needed to use the diode laser in clinical practice, since it could conduce to safety issues.

Some studies used tooth without pulp chamber which may reduce the effectiveness of the activation through laser.

6. CONCLUSION

After analyses, our findings allow us to conclude that laser assisted irrigation was significantly better than conventional irrigation to disinfect the root canal system and remove smear layer and debris. Even if some authors did not find results in this way, it seems that laser devices were superior to other activation devices such as sonic or ultrasonic devices, to achieve the disinfection of the root canal and the removal of debris and smear layer. Furthermore, our findings suggest that laser devices were more effective than conventional irrigation and activation devices in promoting the penetration of both irrigation solution and sealer materials in depth into dentinal tubules. However, further research may be needed to evaluate the efficacity of laser activated irrigation in more complex canals and teeth, in more conservative preparation trough more conservative access cavity and/or more conservative root canal preparation. Furthermore, comparing different laser devices under different settings may lead to optimal configurations. In conclusion continued exploration is needed to fully understand the mechanisms of laser activation and leverage its benefits.

7. BIBLIOGRAPHICAL REFERENCES

1. Gu Y, Perinpanayagam H, Jin DJW, Yoo YJ, Jeong JS, Lim SM, et al. Effect of Different Agitation Techniques on the Penetration of Irrigant and Sealer into Dentinal Tubules. Photomedicine and Laser Surgery. 2017 Feb 1;35(2):71–7.

2. Dhawan S, Jasuja P, Khurana H, Gakhar E, Singh H. A comparative evaluation of the efficacy of erbium: yttrium–aluminum–garnet and diode lasers in smear layer removal and dentin permeability of root canal after biomechanical preparation – A scanning electron microscopy study. J Indian Soc Pedod Prev Dent. 2020;38(1):64.

3. Uslu G, Gündoğar M, Üngör M, Özyürek T, Erkan E, Keskin NB. Investigation of the effectiveness of sonic, ultrasonic and new laser-assisted irrigation activation methods on smear removal and tubular penetration. Lasers Med Sci. 2023 Jan 3;38(1):30.

4. Nasher R, Franzen R, Gutknecht N. The effectiveness of the Erbium:Yttrium aluminum garnet PIPS technique in comparison to different chemical solutions in removing the endodontic smear layer—an in vitro profilometric study. Lasers Med Sci. 2016 Dec;31(9):1871–82.

5. Deleu E, Meire MA, De Moor RJG. Efficacy of laser-based irrigant activation methods in removing debris from simulated root canal irregularities. Lasers Med Sci. 2015 Feb;30(2):831–5.

6. Arslan D, Guneser MB, Dincer AN, Kustarci A, Er K, Siso SH. Comparison of Smear Layer Removal Ability of QMix with Different Activation Techniques. Journal of Endodontics. 2016 Aug;42(8):1279–85.

7. Cheng X, Chen B, Qiu J, He W, Lv H, Qu T, et al. Bactericidal effect of Er:YAG laser combined with sodium hypochlorite irrigation against Enterococcus faecalis

deep inside dentinal tubules in experimentally infected root canals. Journal of Medical Microbiology. 2016 Feb 1;65(2):176–87.

8. Akcay M, Arslan H, Mese M, Durmus N, Capar ID. Effect of photon-initiated photoacoustic streaming, passive ultrasonic, and sonic irrigation techniques on dentinal tubule penetration of irrigation solution: a confocal microscopic study. Clin Oral Invest. 2017 Sep;21(7):2205–12.

9. Lukač M, Lukač N, Jezeršek M. Characteristics of Bubble Oscillations During Laser-Activated Irrigation of Root Canals and Method of Improvement. Lasers Surg Med. 2020 Nov;52(9):907–15.

10. Mancini M, Cerroni L, Palopoli P, Olivi G, Olivi M, Buoni C, et al. FESEM evaluation of smear layer removal from conservatively shaped canals: laser activated irrigation (PIPS and SWEEPS) compared to sonic and passive ultrasonic activation—an ex vivo study. BMC Oral Health. 2021 Dec;21(1):81.

11. Bago I, Batelja-Vuletić L, Tarle A, Sesar A, Anić I. Novel laser activated photoacoustic streaming for removing pulp remnants from round root canals after single file reciprocating instrumentation. Photodiagnosis and Photodynamic Therapy. 2022 Mar;37:102631.

12. Gorus Z. A comparative evaluation of smear layer removal by using different Er:YAG lasers parameters: An İn-vitro scanning electron microscopic study. Niger J Clin Pract. 2018;21(12):1602.

13. Lei L, Wang F, Wang Y, Li Y, Huang X. Laser activated irrigation with SWEEPS modality reduces concentration of sodium hypochlorite in root canal irrigation. Photodiagnosis and Photodynamic Therapy. 2022 Sep;39:102873.

14. Alves D, Decucio D, Alenca, Estrela C, Souza J, Pinheiro A, Estrela C. Effect of Low-Power Diode Laser on Infected Root Canals. Braz Dent J. 2022 May-Jun;

33(3): 8–17.

15. Kumar K, Teoh Y, Walsh LJ. Root canal cleaning in roots with complex canals using agitated irrigation fluids. Aust Endodontic J. 2023 Apr;49(1):56–65.