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The various application of lasers in an endodontic treatment

An integrative systematic review

Barbara Julie Bouhnik

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

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Trabalho realizado sob a Orientação de
"Mestre Luís Caetano"

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RESUMO

Introdução: O Gold standard para a irrigação é uma seringa de NaOCl, que tem uma ação ampla e capacidade para desinfetar e dissolver tecido orgânico, mas tem as suas limitações e pode ser tóxico. Para responder a esta situação, foram desenvolvidas novas abordagens, incluindo lasers. Apesar de existir um interesse crescente na aplicação de lasers durante um tratamento endodôntico, existem várias dúvidas associadas.

Objetivo: Verificar o impacto real dos vários lasers na terapia endodôntica.

Material e métodos: Pesquisa bibliográfica na base de dados PubMed e Scielo, utilizando estes palavras-chave: "Root Canal Therapy", "Laser therapy", "Root canal".

Resultados: Pesquisa bibliográfica nas bases de dados de acordo com os critérios de inclusão produziu 230 estudos, dos quais 19 foram considerados relevantes com o apoio de 2 revisões sistemáticas. Os estudos avaliaram os papéis/habilidades que os lasers podem desempenhar durante um tratamento endodôntico.

Discussão: Para estabelecer a verdadeira eficácia dos lasers, temos de compreender as diferentes técnicas e capacidades que podem ser aplicadas: PIPS (Photon-induced photoacoustic streaming), PAD (Photoactivated Disinfection) e PDT (Photodynamic Therapy) centram-se na capacidade de desinfeção e de remoção de detritos e de smear layer, enquanto PBM (Photobiomodulation) se centram na capacidade a aliviar a dor.

Conclusão: Existe um consenso de que os lasers têm efeitos bactericidas e ajudam a eliminar a smear layer e a aliviar a dor. No entanto, devido à heterogeneidade dos parâmetros, não se pode afirmar que os lasers podem substituir completamente as técnicas convencionais.

Palavra-chave: "Root Canal Therapy", "Laser therapy", "Root canal".

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ABSTRACT

Introduction: The gold standard for irrigation nowadays is a syringe of NaOCl it has a wide action and ability to disinfect and dissolve organic tissue, but it has its limitation and can be toxic. To respond new approaches were developed included lasers. Despite the fact there is a growing interest in the application of lasers during an endodontic treatment, there are several doubts associated with it.

Objective: To ascertain the actual impact of various lasers on endodontic therapy.

Materials and methods: Bibliographic search in the PubMed and Scielo database, , using the keywords: "Root Canal Therapy", "Laser therapy", "Root canal".

Results: The literature search of the databases according to the inclusion criteria yielded 230 studies, of which 19 were considered relevant with the support of 2 systematic reviews. The studies assessed the roles/abilities that lasers can play during an endodontic treatment.

Discussion: To establish the real efficiency of lasers, we have to understand the different techniques and abilities than can be apply: PIPS (Photon-induced photoacoustic streaming), PAD (Photoactivated Disinfection) e PDT (Photodynamic Therapy) focusing on the ability to disinfect and to remove debris and smear layer whereas LLLT or PBM (Photobiomodulation) focusing on the ability to reduce pain.

Conclusion: There is a consensus that lasers have bactericidal effects and help eliminate smear layer and help relieve pain. However, due to the heterogeneity of the parameters, it cannot be said that lasers can completely replace conventional techniques.

Key word: "Root Canal Therapy", "Laser therapy", "Root canal".

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Summary

LISTS OF ABBREVIATIONS, ACRONYMS OR ACRONYMS:

EAI = Sonic irrigation with EndoActivator

ERT= Retreatment endodontic

ET= Endodontic treatment

EV = EndoVac system

LAI = Laser-activated irrigation

NI = Needle irrigation

PAD = Photo activated disinfection

PDT= Photodynamic therapy

PIPS = Photon-induced photoacoustic streaming.

Po = Postoperative

PoP = Postopearative pain

RCP= Root canal preparation

RCT = Root canal treatment

SL = Smear layer

Ss= Stainless steel

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1. INTRODUCTION

Endodontic treatment is an essential care in dentistry for preserving the teeth and preventing potentially dangerous complications. This treatment involves cleaning and disinfecting the root canal systems, followed by a proper sealing to prevent reinfection and promote the resolution of apical periodontitis. Traditionally, mechanical instruments and disinfecting solutions are used for irrigation. The current gold standard for irrigation is a syringe of sodium hypochlorite (NaOCl), which has broad-spectrum action and effective disinfection and organic tissue dissolution properties, although it has limitations and can be toxic (1).

Indeed, the goal of the practitioner during endodontic treatment is not only to eliminate bacteria but also to remove debris and the smear layer that forms after instrumentation. Debris consists of particles of dentin and residual pulp tissue. The Smear layer is " *an amorphous, irregular, tenacious structure consisting of dentin, pulp tissue remnants, and microbial elements that occlude dentinal tubule openings* "(Turkel et al., 2017, p. 1) which makes it difficult to remove but its removal is essential for a successful treatment (2)

To address these challenges, new approaches have been developed, including the use of lasers (Light Amplification by Stimulated Emission of Radiation). The interaction between a laser beam and tissue results in the conversion of absorbed laser energy into thermal energy, which induces alterations in the tissue's internal structure (1).

The first utilization of lasers during endodontic treatment was reported by Weichman and Johnson in 1971. Since then, various lasers have been developed for endodontic applications. Currently, there are multiple types of lasers, but in this review, we will focus on the four main types: diode laser, Er:YAG, Er,Cr:YSGG, and Nd:YAG. Diode lasers cover a wide range of the electromagnetic spectrum within the visible and infrared range, from 635 nm to 980 nm. Due to their higher absorption coefficient in water, they have a lower penetration depth into dentin, allowing better penetration of laser light. Numerous studies have indicated that diode lasers exhibit antibacterial and analgesic effects (1,3). Similarly, Erbium lasers, such as Er:YAG (2940 nm) and Er,Cr:YSGG (2780 nm or 2940 nm), have higher absorption in water and hydroxyapatite. This property can translate to antibacterial effect but also their ability to remove hard and soft tissues and including the Smear layer (1,4).

Finally, the Nd: YAG laser, also known as the Neodymium laser has higher absorption in melanin and dark tissues than in water. Nonetheless it has shown antibacterial effect and removing dentinal debris, including the Smear layer due to his higher thermal heating effect on the environment and the inside of bacteria (1,5).

In addition to these lasers, various techniques using Low-Level Laser Therapy (LLLT) have been developed to aid in the root canal preparation process during endodontic treatment. Photobiomodulation (PBM) is often used for reducing the pain after an endodontic treatment (6–11). Different laser-activated techniques, such as Photon-induced photoacoustic streaming (PIPS), photo-activated disinfection (PAD), and photodynamic therapy (PDT), have been developed to assist in canal cleaning (2,4,12–15).

Despite the growing interest in the application of lasers during an endodontic treatment, several concerns remain. These concerns stem from the lack of reliable research that clearly demonstrates the advantages of laser use compared to current techniques but also a lack of standardised technique and/or protocol (16)

2. OBJECTIVES

2.1 Primary objective

This integrative systematic review aims to ascertain the actual impact of different lasers on endodontic therapy.

2.2 Secondary objectives

→ To analyze and compare the variations in technical methodologies and their corresponding impacts on the different phases of canal preparation.

→ If lasers can be used to replace traditional techniques for canal preparation, specifically in terms of disinfection and removal of the smear layer.

→ To assess the impact of lasers on post-endodontic treatment pain.

3. MATERIALS AND METHODS

3.1 PICO question

Do therapeutic lasers have an impact on the endodontic microbiota and post-endodontic treatment pain?

3.2 PICO model

In this study, the aim is to investigate the diverse impacts of lasers during an endodontic treatment. Therefore, the eligibility criteria will adhere to those of a quantitative study.

Table 1: PICO Model (Quantitative questions)

Population (P)	→Adult patients aged 18 years or above who desire to undergo either endodontic therapy (ET) or retreatment (RET), with or without the presence of a periapical lesion. →Teeth that have previously undergone ET, whether they are monoradicular or multiradicular.
Intervention (I)	→Laser-assisted disinfection technique during ET. →Utilization of laser for minimizing PoP following an ET.
Control (C)	Teeth that underwent an ET without the administration of any laser treatment or placebo.
Outcome (O)	The potential impacts of various lasers on canal disinfection during an ET, as well as their potential effects on PoP.

3.3 Research strategy

With the aim of fulfilling the objective of this review, a comprehensive electronic bibliographic search was carried out. Two databases, namely PubMed MeSHTerm Database and Scielo, were utilized to address the research question with the keyword "Root canal Therapy", "Laser therapy" and "Root canal". Moreover, the selection of relevant articles was made using the PICO criteria.

→The Advanced research in PubMed were *("Root Canal Therapy"[Mesh]) AND "Laser therapy "[Mesh].*

→The Advanced research in Scielo were *(*laser therapy) AND (root canal).*

3.4 Inclusion criteria

For article selection, the eligibility inclusion criteria encompassed comparative studies, randomized controlled trials, case reports, clinical studies, observational studies, controlled clinical trials, and clinical trials conducted between 2012 and 2023.

The studies needed to assess the defined topic and establish objectives relevant to the subject matter described in the title and/or abstract.

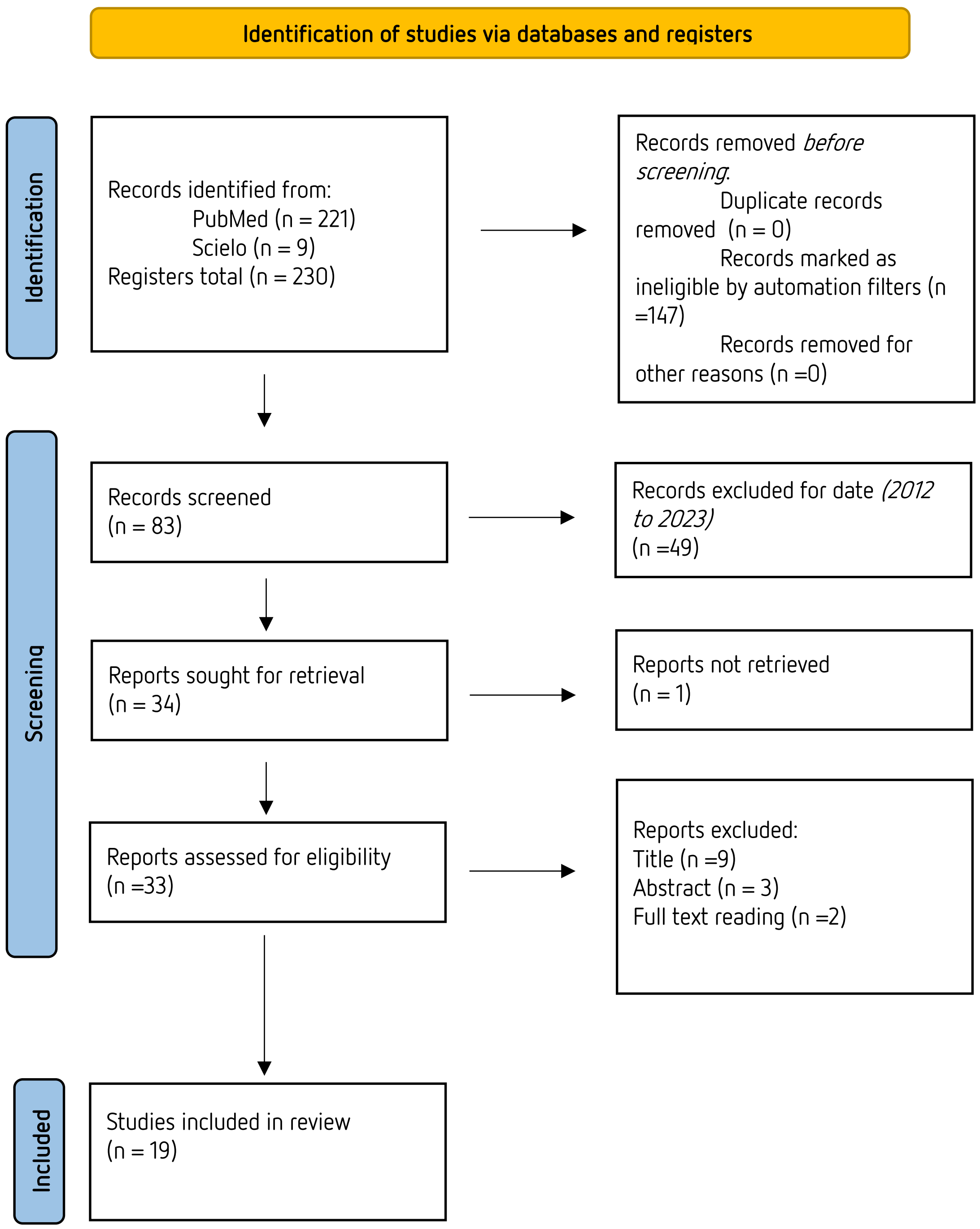
The selected languages were English, French, or Portuguese, and the studies were required to involve human teeth that underwent an endodontic treatment.

3.5 Exclusion criteria

All publications dating back more than eleven years (prior to 2012), which were deemed irrelevant to the study after a thorough assessment of their title and abstract, and were inaccessible in English, Portuguese, or French, were excluded. Additionally, all studies pertaining to animal subjects and children were excluded.

Following the removal of articles that did not meet the inclusion criteria, without reviewing their titles or abstracts, a total of 34 articles were identified, comprising of 25 articles from the PubMed MeSHTerm Database and 9 articles from Scielo. Upon scrutinizing the titles and abstracts of the retrieved articles and removing any duplicates, a final set of 19 articles were obtained (Figure 1).

Figure 1: PRISMA 2020 flow diagram of the articles selected for our study.



4. RESULTS

After conducting a thorough analysis of the 19 relevant articles identified in our study (Figure 1), we extracted the following information: article details (title, authors, year of publication, study type), objectives, methods, results, and conclusions for each study. These findings were then documented in Table 2. Furthermore, we included two systematic reviews for additional support.

Table 2: Overview of the results of the articles selected by our study.

Articles	Objectives	Materials/Methods	Results	Conclusion
Title: Evaluation of effect of low-level laser therapy with intracanal medicament on periapical healing: A randomized control trial (6) Author/Year: Shah et al., 2021 Study type: Randomized control trial	To evaluate the role of LLLT in periapical healing and PoP.	40 patients with periapical lesion on monoradicular teeth were selected and have undergone an ET and then were assigned randomly into two groups: Group I Conventional root canal therapy along with LLLT: (Three sessions was given at 0, 7th and 14th day). →The parameters set were 660nm diode laser with an output of 100mW and 1J/cm² for 80s. Group II: Conventional root canal therapy only. the same protocol of root preparation was applied to both groups: Radiographs were obtained and assessed at baseline, 3-, 6- and 9-months Po. → The VAS pain scale was assessed at 0, 7th and 14th day respectively.	→Periapical lesion: Significant differences were noted in reduction of periapical lesion at 3- and 9- months follow-up. The healing was better in Group I that received LLLT with the RCT. → For PoP: the immediate pain, at 7th and 14th was lower in Group I than Group II.	The application of LLLT during the treatment resulted in the lower pain intensity experienced by the patient. Also, it was observed that the lesion size reduction was maximum in the laser group than the non-laser group.

Title: Effect of low-level laser therapy on postoperative pain after single-visit root canal retreatment of mandibular molars- A randomized controlled clinical trial (7) Author/Year: Fazlyab et al., 2021 Study type: Randomized control trial.	To compare the effect of low-level laser therapy (LLLT) on PoP after single-visit RCT on mandibular molars.	36 healthy patients who required root canal retreatment on symptomatic first or second mandibular molars. The patients were randomly assigned to treatment groups: - LLLT group : diode laser 980 nm set at 6.89 W/cm^2, 0.5 W, for15s. - Placebo group, the laser handpiece was placed at the same location, but not activated. Patients record their pain levels at 4, 8, 12 and 24 h and 2, 3 and 7 days on VAS scales.	The most intense pain was: →LLLT group, within 24 and 48 hours of treatment. →Placebo group within 4 h Po. At the 4 h interval, the severity of the pain was much lower in the LLLT group.	LLLT reduced the intensity of PoP only at 4 h after retreatment.
Title: Bactericidal Effect of 2780 nm Er,Cr:YSGG Laser Combined with 940 nm Diode Laser in Enterococcus faecalis Elimination- A Comparative Study (17) Author/Year: Tokuc et al., 2019 Study type: Comparative study.	To compare the efficacy of various Er,Cr:YSGG disinfection methods, especially the combined Er,Cr:YSGG and Diode laser application.	95 extracted monoradicular premolars with similar canal dimensions were selected. The teeth have undergone an ET and then were sterilized and were infected with Enterococcus faecalis. The teeth were randomly divided into five groups (n=15): - Group 1 :5% NaOCl ; - Group 2 : Er,Cr:YSGG; - Group 3 : Er,Cr:YSGG +5% NaOCl ; - Group 4: Er,Cr:YSGG + Diode ; - Group 5: control group. →The parameters set were: - Er,Cr:YSGG : 2780 nm with an output of 1,25 W for 4 times 10s. – Diode laser: 940 nm with an output of 4,5W for 4 times 10s.	→ Maximum bacterial elimination occurred in the Er,Cr:YSGG + NaOCl group → Higher bacterial counts in the Er,Cr:YSGG and Er,Cr:YSGG + Diode groups than in the NaOCl group.	The most successful E. faecalis elimination was obtained from laser-activated irrigation group. Because the combined application of laser Er, Cr:YSGG and Diode gives none conclusive results, more studies with larger sample sizes are needed.

Title: Effect of Root Canal Disinfection with a Diode Laser on Postoperative Pain After Endodontic Retreatment (18) Author/Year: Genc Sen & Kaya, 2019 Study type: Randomized control trial.	To assess the role of a diode laser in the disinfection of root canal and the level of pain after an ERT	84 patients for ERT in monoradicular teeth were divided into two groups: - Group 1: Activated Diode laser - Group 2: Placebo. → Parameters set were: 940nm with an output of 1W. This process was repeated four times with an interval of 20 seconds between application. The pain was evaluated on the NRS scale on the 1st, 2nd, 3rd and 4th days after receiving the treatment.	In group 1 the PoP was far less on the first two days than in group 2 but this distinction faded after three days. Nonetheless the intake of analgesic drug and percussion pain were lesser in group 1 even after the third and fourth day.	Activated diode laser can decrease the pain after an ERT; but other studies are essential to comprehend the effect of different type of laser and their parameters.
Title: Effect of Low-level Laser Therapy on Postoperative Pain in Molars with Symptomatic Apical Periodontitis: A Randomized Placebo-controlled Clinical Trial (8) Author/Year: Doğanay Yıldız & Arslan, 2018 Study type: Randomized Placebo-controlled Clinical Trial	To assess the impact of LLLT on PoP in the mandibular molars with symptomatic apical periodontitis.	42 patients with symptomatic apical periodontitis needing an ET were divided in 3 groups (n=14): - Group 1: Control - Group 2: Placebo - Group 3: Laser activated →Parameters set were: Diode laser 970 nm with an output of 0.5 W for 30s The intake of ibuprofen 400mg was also register. The pain was evaluated on the VAS on the 1st, 3rd, 5th, 7th, and 30th days after the treatment.	In group 3 the PoP was far less on the first and third days than the other groups. However, there was no difference between the 3 groups in terms of percussion pain level.	The application of LLLT has led to a decreased of the pain levels. This study has limitations, and it is essential to carry out other studies.
Title: Effect of photobiomodulation therapy on postoperative pain after endodontic treatment: a randomized, controlled, clinical study (19) Author/Year: Lopes et al., 2019	To evaluate the impact of PBM on the pain level after an ET using a low-level laser.	60 patients were selected and divided randomly into 2 groups. The same ET was realised by the same operator on mandibular molar teeth. - Group Control - Group PBM: 808 nm with an output of 0,10 W and 2,5J for 25s. → Then patients record their pain levels on the VAS	→The level of pain was five times lower in the PBM group after 24h. There was also a lower intensity of pain after 6h. → In the PBM there was less extrusion than in the control group.	The utilisation of a the PBM with a low-level laser resulted in the decreased of the pain level after an ET especially 24h after.

Study type: Randomized Placebo-controlled Clinical Trial		and NRS scales after 6,12 and 24h after treatment. → The pain assessment was analysed by a third person who did not know about group assignment.	Furthermore, the extrusion of the filling material was associated with the augmentation of the pain.	
Title: Effect of preoperative ibuprofen in controlling postendodontic pain with and without low-level laser therapy in single visit endodontics: A randomized clinical study (9) Author/Year: Nabi et al., 2018 Study type: Randomized clinical trial.	To assess the capacity of LLLT to relieve pain after an ET and to compare its effect with the intake of ibuprofen	120 patients were selected and have undergone an ET and then were and divides into 4 groups (n=30). -Group A: Intake of 400mg ibuprofen, 1h before treatment -Group B: Application of LLLT -Group C: Ibuprofen 1h before + LLLT -Group D: Control group → Parameters set were: Diode laser 905 nm with an output of 60 mW for 3 min Then patients record their pain levels at 4, 8, 12, 24 and 48 h on Heft and Parker scale.	→ There is less pain in groups A, B, C than in the group control. The most efficient was the group C. Nonetheless the laser group have a better efficacity in the duration than just with ibuprofen.	The application of LLLT can be used as an alternative of the use of anti-inflammatory steroids drug to alleviate the pain.
Title: Comparative Safety of Needle, EndoActivator, and Laser-Activated Irrigation in Overinstrumented Root Canals (20) Author/Year: Sen & Kaya, 2018 Study type: Comparative study	To assess and compare the risk of NaOCl irrigation with NI, EAI and LAI in the over instrumental root canal.	30 single root teeth were extracted and have undergone an ET and then were divided into 2 groups which experience 3 types of irrigation techniques (NI, EAI and LAI), (n=15) - Group 1: Under-instrumented - Group 2: Over-instrumented → LAI parameters set were: Er,Cr:YSGG 2780 nm with an output of 1.5 W, 75 mJ for 10s → A modified container-foam model was used to	→ More extrusion in group 2 than in group 1 with EAI and LAI → In group 2 EAI extruded significantly more. → In group 1 there was no difference between the 3 techniques.	The three techniques are safe to use when the apex of the tooth is intact. Nonetheless the risk can be greater with EAI and Lai when the canal is over-instrumented.

		collect apically extruded NaOCl.		
Title: Effect of Low-level Laser Therapy on Postoperative Pain after Root Canal Retreatment: A Preliminary Placebo-controlled, Triple-blind, Randomized Clinical Trial (10) Author/Year: Arslan et al., 2017 Study type: Randomized Clinical Trial	To assess the impact of LLLT on PoP in the mandibular molars with periapical lesions	36 patients with periapical lesions have undergone an ET and then were divided in 2 groups (n=18): -Group 1: Diode laser activated -Group 2: Placebo group → Parameters set were: Diode laser 970 nm with an output of 0.5 W for 30s → The pain was evaluated on the VAS on the 1st, 2nd, 3rd, 4th, 5th, 6th and 7th days after the treatment. → The pain assessment was analysed by a third person who did not know about group assignment.	The Pop was reduced with the LLLT on the 4th day, but the difference was not significative after. However, the intake of analgesic was far less in the group 1 than the group 2 (1:9).	The application of low-lever laser can help reduced the pain after an ERT.
Title: Comparison of Three Final Irrigation Activation Techniques: Effects on Canal Cleanness, Smear Layer Removal, and Dentinal Tubule Penetration of Two Root Canal Sealers (2) Author/Year: Turkel et al., 2017 Study type: Comparative study	To assess and compare the effect of disinfection, SL removal and intrusion of the sealers with three irrigation techniques: NI, EV and PIPS.	142 monoradicular teeth have undergone an ET and then were divided in 4 groups: -Group 1 (n=13): Control -Group 2 (n=43): NI technique with 5% NaOCl +17% EDTA -Group 3 (n=43): EV technique with 5% NaOCl +17% EDTA for 30s -Group 4 (n=43): PIPS technique with 5% NaOCl +17% EDTA for 30s → Parameters set were: Er:YAG 2940 nm with an output of 0.3 W, 20 mJ for 30s.	→ SL removal and disinfection: Group 4 better than group 1,2 and 3 at removing debris. No difference between group 3 and 4 for SL removal → Intrusion in dentinal tubule: Group 4 better than the other groups with AH Plus.	The three techniques were quite similar regarding the disinfection, SL remover and intrusion of the sealer.
Title: The Effect of Diode Laser on Planktonic Enterococcus faecalis	To assess the impact of a diode laser in the removal	128 monoradicular teeth were extracted and have undergone an ET and then were contaminated with E.	Group 2 and 4 were able to kill all the bacteria.	Diode laser+ NaOCl was not more powerful to decontaminate

in Infected Root Canals in an Ex Vivo Model (3) Author/Year: Cretella et al., 2017 Study type: Ex Vivo study	of E.Faecalis and bacteria	faecalis and divided into 5 groups (n=24): - Group 1: Saline irrigation (Control); - Group 2: 5.25% NaOCl for 3 min; - Group 3: Saline+ Diode laser; - Group 4: 5.25% NaOCl + diode laser. - Group 5: Saline with methylene blue + Diode laser → Parameters set were: 810nm with an output of 8W and radiant power of 2.5W, 75J. This process was repeated three times 30s. → The Uro-Quick system and Pearson's chi-square test was used to analyzed the data.	Group 3 reduction of the number of bacteria but was less effective that NAOCL, but more than group 1.	the canal than just NaOCl.
Title: Use of a 660-nm Laser to Aid in the Healing of Necrotic Alveolar Mucosa Caused by Extruded Sodium Hypochlorite: A Case Report (11) Author/Year: Bramante et al., 2015 Study type: Case Report	Describing the treatment of an extrusion of NAOCL using an LLLT.	Extrusion of 1% NaOCl during an ERT on a right maxillary central incisor, the canal was rinsed with a saline solution and antibiotics were given 8h/7days.A necrosis area was form. → Applications of LLLT 660 nm 2 times per week for 4 weeks.	Complete healing of the necrosis area.	LLLT help in this case of the extrusion of 1% sodium hypochlorite.
Title: Comparison of the antibacterial effect and smear layer removal using photon-initiated photoacoustic streaming aided irrigation versus a conventional irrigation in single-rooted canals: an in vitro study (4)	To study the capacity of disinfection and SL removal of PIPS in comparison with the use of NI in the apical area during ET.	96 monoradicular teeth were extracted and have undergone an ET and then were divided into experiment (n=48) and split into 6 groups: →Experiment 1: Teeth were inoculated with Enterococcus faecalis. →Experiment 2: Removal of SL was scored by SEM examination.	→ Antibacterial: Group 2, 5 and 6 could remove 99,99% of bacteria. → SL removal: - Coronal and middle third: Group 5 and 6 were more	PIPS+ NaOCl or the conventional NI with NaOCl + EDTA have the same capacity of disinfection and SL removal.

Author/Year: Zhu et al., 2013 Study type: In vitro study		- Group 1: Using NI (Control) - Group 2: 3% NaOCl - Group 3: 0,2% CHX - Group 4: 17% EDTA - Group 5: 3% NaOCl +17% EDTA. - Group 6: PIPS +3% NaOCl → Parameters set were: Er:YAG 2940nm with an output of 0.3 W, 20 mJ for 60s.	efficient at removing SL. - Apical third: No groups succeeded.	
Title: An in vitro evaluation of microtensile bond strength of resin-based sealer with dentin treated with diode and Nd:YAG laser (5) Author/Year: Das et al., 2013 Study type: In vitro study	To compare and evaluate the capacity of SL removal after using a diode laser and Nd:YAG to increase the microtensile bond strength of AH-Plus	30 teeth were chosen to undergo an ET and then were divided into 3 groups (n=10): One tooth of each group was scored and observed by SEM. -Group 1: Control -Group 2: Diode laser → Parameters: 940 nm with 125 mJ for 20s. -Group 3:Nd:YAG → Parameters: 1064 nm with 100 mJ for 20s.	Group 3 was capable of removing the SL whereas the Group 2 removed partially the SL.	The group 3, using Nd: YAG was more efficient at removing the SL than the other group and as a result will increase the microtensile bond of the sealer.
Title: Qualitative comparison of sonic or laser energisation of 4% sodium hypochlorite on an Enterococcus faecalis biofilm grown in vitro (21) Author/Year: Seet et al., 2012 Study type: In vitro study	To assess qualitatively and compare the effect of disinfection of EAI and Er,CR:YSGG on teeth infected with E.Faecalis.	58 monoradicular teeth were extracted and have undergone an ET and then were contaminated with E. faecalis and split into 6 groups: - Group 1: Saline (Control) - Group 2: Saline+ EAI - Group 3: Saline + LAI - Group 4: 4% NaOCl - Group 5: 4% NaOCl +EAI - Group 6: 4% NaOCl +LAI → LAI parameters set were: Er,Cr:YSGG 2780 nm with an output of 0.25 W, for 4 times 5s.	→Group 2 vs Group 3: Better removal of bacteria with simply a laser than the EAI. → Group 6 was the most efficient at removing debris and bacteria with no level of E.Faecalis.	The application of Er,CR:YSGG+ NaOCl was overall the most efficient for reducing the bacteria and debris.
Title: Effectiveness of photoactivated disinfection (PAD) to	To assess the capacity of PAD in removing	Two experiments were executed:	→ Experiment 1: The more the energy dose	PAD was capable of killing E.Faecalis better in planktonic

kill enterococcus faecalis in planktonic solution and in an infected tooth model (12) Author/Year: Yao et al., 2012 Study type: Comparative study	E.Faecalis in planktonic solution and in teeth.	1- 132 Glass tubes contaminated and then split into 16 groups using a diode laser with various energy dose (0,5 to 5,5J), Output (50 or 100mW) and with duration (10 to 55s). 2- 60 monoradicular teeth have undergone an ET and then were infected and then split into 3 groups (n=20): - Group 1: PAD - Group 2: 5,25% NaOCl - Group 3: Saline → PAD parameters set were: Diode laser 635 nm with an output of 100mW, 15J for 150s.	and output or duration is the more effective it is. → Experiment 2: NaOCl could eliminate practically all bacteria. PAD was more efficient than the saline group. PAD was a slightly less effective than NaOCl.	solution than in root canal. 5,25% of NaOCl was no more effective. The more the energy dose and output or duration is the more effective it is.
Title: Decontamination efficacy of photon-initiated photoacoustic streaming (PIPS) of irrigants using low-energy laser settings: an ex vivo study (13) Author/Year: Pedullà et al., 2012 Study type: Ex vivo study	To study the capacity of disinfection of PIPS with Er,CR:YSGG.	148 monoradicular teeth were extracted and have undergone an ET and then were contaminated with E. faecalis and then divided in 4 groups (n=32): -Group A: PIPS technique + Distilled water -Group B: PIPS technique + 5% NaOCl -Group C: Distilled water -Group D (n=43): 5% NaOCl for 30s → Parameters set were: Er,CR:YSGG 2940 nm with 20 mJ for 30s.	→Group B was the most efficient in killing E.Faecalis (93,75%) but there wasn't a significant differences with group D. →Group A was significantly more efficient than group C.	There was no discernible variation in the antibacterial effect between using PIPS technique and not when NaOCl was used.
Title: Effect of low-power diode laser on infected root canals (14) Author/Year: Alves et al., 2022 Study type: Comparative study	To assess the capacity of PDT in killing E.Faecalis	21 moradicular teeth were extracted and the crown removed, and have undergone an ET and then infected with E.faecalis. 21 teeth were split into 7 groups: -Group 1: RCP with NiTi+ 2,5%NaOCl + 17% EDTA +PDT	→ Antibacterial: No groups succeeded at removing all E.Faecalis. Group 1, 2 could remove the most of	PDT couldn't killed all Faecalis and remove all the SL but was able to be more efficient than conventional irrigation technique.

		-Group 2: RCP with Ss+ 2,5%NaOCl + 17% EDTA +PDT -Group 3: RCP+ NiTi+ 2,5%NaOCl + 17% EDTA -Group 4: 2,5% NaOCl + 17% EDTA -Group 5: 2,5%NaOCl + 17% EDTA +PDT -Group 6: negative Control -Group 7: Positive Control → Parameters set were: Diode laser 660 nm ± 10 nm with an output of 100 mW for 3 min. → Each group was scored and observed by SEM, Wilcoxon test and Mann-Withney.	E.Faecalis (90% and 92%). → SL removal: Coronal, middle third and apical third: Group 1, 2 and 5 were more efficient at removing SL.	
Title: Evaluation of the dentin changes in teeth subjected to endodontic treatment and photodynamic therapy (15) Author/Year: LACERDA et al., 2016 Study type: Observational study	To investigate the modification morphological and the quantity of apical leakage after using PDT.	40 monoradicular teeth have undergone an ET and then were divided into two groups: -Group 1: 5,25% NaOCl + 17% EDTA -Group 2: 5,25% NaOCl + 17% EDTA+ PDT → Parameters set were: Diode laser 660 nm with an output of 100 mW, 12J for 5 min. → Each group was scored and observed by SEM.	G2 was far more efficient at removing debris and removing SL than Group 1.	PDT was efficient to remove the debris and SL. The application of laser help at increasing the permeability of the tubule dentin.

5. DISCUSSION

In order to determine the true effectiveness of lasers, it is crucial to comprehend the various techniques and capabilities that can be employed during an endodontic treatment.

5.1 Lasers' techniques

To assist practitioners during endodontic treatment, several techniques have been developed to address specific issues such as effective disinfection, debris/Smear layer removal, and post-operative pain reduction.

The techniques of PIPS, PAD, and PDT primarily aim to achieve thorough disinfection and debris removal, while PBM focuses on alleviating post-operative pain (2–15,17–21).

5.1.1 PIPS technique

Photon-induced photoacoustic streaming (PIPS) is a relatively new technique that falls under the category of laser-activated irrigation (LAI). Specifically, this technique is associated with Erbium lasers such as Er:YAG and Er,Cr:YSGG. It consists by using a low-energy laser which will interacts with the water molecules present in the irrigation solution. The photon-induced impulsions will create a wave that will cause a movement of fluids within the tissues, thereby enhancing the penetration coefficient of the irrigant utilized (2).

Additionally, one unique aspect of this technique is that the laser tip remains confined to the coronal portion of the tooth, limited to the pulp chamber or a maximum of 4 mm into the root (2,4,13).

Based on the various studies included in this review, the association with Erbium lasers seems to enhance the efficacy of the irrigant in terms of optimizing disinfection and removing debris and the smear layer located within the canals. However, due to the particularity of the location of the laser tip, adequate disinfection, and debris removal in the apical third of the canal may be hindered (2,4,13).

5.1.2 PAD and PDT techniques

The Photoactivated Disinfection (PAD) and the Photodynamic Therapy (PDT) are similar techniques used for disinfection of the root canal, employing a photosentizer and a red light, but they differ by their modes of operation (12,14,15).

On one hand, PAD involves the combination of an aqueous solution containing a photosensitizer with a non-thermal red light of 635 nm to activate the solution. This technique relies on the interaction of both components for effective disinfection (12). Photosentizers are organic dyes of the phenothiazine family, which includes tolonium chloride and methylene blue. With the specific wavelengths of 635 nm, the tolonium chloride is the most commonly used because it can absorb light from 620 to 660 nm. When exposed to laser light at its absorption peak, photosensitizers release nascent oxygen, leading to an oxidative reaction that damages bacterial cell walls and eliminates them. One notable aspect of this technique is its specificity in targeting bacteria within the root canal while sparing healthy tissue, unlike conventional irrigants such as NaOCl (12).

On the other hand, PDT, also involves the use of a photosensitizer and red light, but with this time it is a visible light source that will produces heat. However, the process of elimination remains the same; Indeed, the photosentizer , often methylene blue in this technique, reacts with visible and thermal light, triggering a chemical reaction. This interaction releases reactive oxygen species (ROS), free radicals, or singlet oxygen, which interact with the bacterial molecular structure, leading to the destruction of cytoplasmic membranes or DNA, there by killing the bacteria (14,15).

5.1.3 LLLT or PBM technique

Low-level laser therapy (LLLT) or Photobiomodulation therapy (PBM) is an established technique that has been in use since the 1970s (10). Initially, LLLT was primarily utilized to alleviate pain in individuals undergoing orthodontic treatment with fixed appliances. However, its application has expanded to various fields of dentistry to aid in pain reduction during or after treatment.

This technique (LLLT) consists by using a Classe III laser with an output of less than 0.5 W commonly referred to as soft or cold laser (7,9). One notable feature of this laser is that it does not generate heat, sound, or vibration, making it non-invasive and safe for tissue application (7). It utilizes visible red light which ranges from 600-700 nm and near-infrared spectrum ranges from 780-1100 nm.

5.2 Abilities of Lasers

5.2.1 Antibacterial effect

The success of an endodontic treatment primarily relies on effective canal instrumentation (3). This stage can be challenging due to the anatomical variations of teeth/canals, such as narrow or curved canals, as well as the presence of persistent bacteria (4,17). Indeed, it is important to consider that the use of traditional disinfection methods, such as chemical disinfection using NaOCl, which presents health risks due to its cytotoxicity and ability to cause tissue necrosis, is not considered sufficient to ensure effective disinfection (4,21). Studies have shown that even after conventional file preparation and NaOCl irrigation, canals can still harbor 40-60% of bacteria, indicating limited penetration and decontamination of the root canal system, especially in complex anatomies and depending on the bacterial nature (13) .

Actually, there are multiple species of bacteria that inhabit root canals, and among them, Enterococcus faecalis is considered the most resistant to treatment. *« E.faecalis is a gram-positive facultative anaerobic bacterium, [...] can survive in unsuitable conditions within the canal, penetrate into deeper layers of dentin, and form on intra- and extraradicular biofilms. It shows resistance to phagocytes, antibodies, and antimicrobial agents."* (Tokuc et al. 2019). This bacterium is often associated with post-endodontic treatment infections (17).

The application of lasers during the instrumentalization process has been implemented to enhance the disinfection process. Indeed, PDT technique with a 660 nm laser diode (output: 100 mW for 180s) has been shown to achieve a 90% elimination of E. faecalis, compared to 61.61% with conventional techniques using 2.5% NaOCl and 17% EDTA (14).

However, some studies suggest that a more effective approach for optimizing disinfection is to combine lasers with an irrigant. Laser-activated irrigation (LAI) can enhance the bactericidal effect of the irrigant and improve its ability to kill bacteria. For example, the use of the Erbium Er,Cr:YSGG laser (2780 nm, output: 0.25 W for 20 s) in combination with 4% NaOCl has successfully eliminated all bacteria, including E. faecalis (21). Similar finding was obtained in the study by Tokuc et al., 2019 with the elimination of almost all bacteria present in the canal (17).

On the contrary, several studies have concluded that the use of lasers alone or in combination with an irrigant is not significantly more effective than using NaOCl alone. Indeed, several studies have found that the addition of laser therapy to NaOCl irrigation does not significantly improve the effectiveness of the treatment compared to using an irrigant alone (3,4,12,13). For instance, Zhu et al., 2013, found that 3% NaOCl or Er:YAG + 3% NaOCl could remove 99.99% of the bacteria (4). Cretella et al., 2017 also reached a similar conclusion when using a laser diode with 5.25% NaOCl, finding that the combined treatment did not provide significant benefits over using NaOCl alone (3).

Nevertheless, the divergence in results emphasizes the importance of considering factors such as the type of laser used (Erbium or diode), its parameters, and the concentration of the irrigant According to Yao et al., 2012, laser efficiency depends on three key parameters: irradiation time, output power and energy dose. For example, using the PAD technique with an irradiation time of 45 seconds, an output power of 100 mW and an energy dose of 4.5 J, a total elimination of E. faecalis can be achieved (12). However, these parameters are not necessarily suitable for other techniques or laser types.

Moreover, it is crucial to note that inappropriate parameters combined with an irrigant can increase the risk of irrigant extrusion and potential damage, leading to treatment failure (20,21).

5.2.2 Smear layer and Debris removal

Clinically, the instrumentalization process is also meant to remove the smear layer and debris through mechanical and chemical action. *"The smear layer will act as a barrier"*(Das et al., 2013; Turkel et al., 2017) that hinders the sealers' adhesion and penetration into the dentinal tubules, ultimately impeding the complete locking and adhesion of root canal filling material to the dentinal wall (2,5).

Of all the studies encountered, most of them have shown that the use of a laser helps to eliminate debris and the smear layer even if it is not always complete, especially at the apical third. Indeed, the main difficulty encountered by using a laser for removing debris/ smear layer is the ability of being able to remove it in the apical third. Nevertheless, the use of a laser has been demonstrated to be effective in the coronal and median third (2,4,5,14,15).

Actually, the application of LLLT may lead to an increase in temperature, resulting in a photoablative effect. When a laser is used on the dentin, it results in the absorption of its energy by mineral structures like phosphate and carbonate, causing a disruption in the crystalline arrangement due to the heat generated. Laser-induced temperature rise can lead to the melting of dentinal tissues, followed by recrystallization and crystal decomposition due to rapid cooling (5,14).
In addition, the use of low-level laser therapy (LLLT) helps minimize temperature increase to prevent tissue carbonization (14).

Studies by Alves et al. (2022) as well as LACERDA et al. (2016), have reported that the PDT technique (using a Diode laser with a wavelength of 660 nm and a power of 100 mW for 3-5 minutes) effectively removes debris and the smear layer without damaging the dentin (14,15).

The use of the Nd:YAG laser, known for its bactericidal properties, has been proven to be highly effective in eliminating the smear layer, even in the apical third. Das et al. (2013), conducted an in vitro study demonstrating that the use of this laser resulted in debris and smear layer removal, leading to the opening of most dentinal tubules and improved sealant adhesion (5).

According to Zhu et al. (2013), the Erbium Er:YAG laser (2940 nm, 0.3W, 20mJ, for 60s) in combination with the PIPS technique resulted in slightly better debris and smear layer removal compared to the use of 3% NaOCl + 17% EDTA at the first and second thirds of the root. Additionally, this study found that the addition of EDTA acted as an enhancer. (4).

However, Turkel et al. (2017) found that the use of laser in the same PIPS technique was equally effective in removing debris and smear layer as the conventional technique that only used NaOCl + EDTA (2).

5.2.3 Analgesic effect

One of the drawbacks of endodontic treatment is the pain it causes. In fact, between 3% and 58% of patients may experience severe pain after treatment using conventional techniques (6–9). This postoperative pain is usually due to the extrusion of debris outside the apex of the tooth during the instrumentalization phase, which will trigger excessive stimulation of the C-type nerve fibres present in the periodontal ligament by mediators such as prostaglandin, leukotrienes, bradykinin, and serotonin. This nerve hyperstimulation prolongs the healing process and intensifies the pain (7,8).

According to all the articles encountered in this review, the LLLT technique was able to significantly reduce pain following endodontic treatment (6–11,18,19). These results can be attributed to the beneficial effects of visible red light emitted by a laser on pain relief.
In one hand, LLLT improves blood circulation, lymphocytes, and osteoblasts in a positive way, it increases cellular respiration and the release of histamine and neurotransmitters, while inhibiting the production of inflammatory factors (6,7,19).This inhibition is due to the increased production of inhibitory prostaglandins such as PGI2. Indeed, this inhibition increases the function of fibroblasts, which will stimulate collagen regeneration and ATP production, thus accelerating tissue healing and reducing pain (6,7,19).

Secondly, LLLT eliminates pain-inducing substances such as substance P, histamine and dopamine and induces anti-inflammatory effects by inhibiting the cyclooxygenase-2 pathway (7). It also increases lymphatic drainage and changes the permeability of the cell membrane to calcium, sodium and potassium ions, which explains its analgesic effects (7).

Lastly, LLLT increases levels of immunoglobulins and lymphokines as well as the production of analgesic hormones such as beta-endorphin and encephalin, and raises adrenocorticotropic hormone (ACTH) levels, thus contributing to pain relief (7).
Indeed, according to Fazlyab et al. (2021), the maximum pain felt when using the laser after 24 and 48 hours remains lower than the maximum pain felt after using the traditional technique (7). Additionally, according to Shah et al. (2021), this reduction in pain remains significant even after a follow-up of 3 and 9 months (6).

Moreover, due to its anti-inflammatory and analgesic effects, the use of LLLT has shown advantages in the presence of periapical lesions. Studies by Arslan et al. (2017); Doğanay Yıldız & Arslan, 2018; Fazlyab et al. (2021); Shah et al. (2021), have demonstrated that the use of lasers facilitates faster and less painful healing of periapical lesions without damaging the surrounding tissue (6–8,10).

Futhermore, traditional pain relief methods involve the prescription of acetaminophen, antihistamines, or NSAIDs like ibuprofen. However, these drugs can have various side effects and limitations, which makes it interesting to explore non-pharmaceutical techniques. In fact, according to Nabi et al. (2018), LLLT could replace the use of ibuprofen for controlling post-operative pain (9).

6. LIMITATION

It is important to acknowledge that despite the efforts made to conduct a comprehensive systematic review, this study has certain limitations that should be considered when interpreting the results.

One of the limitations encountered is the quality of the studies. Indeed, only the articles addressing the pain relieving capacity of the laser can be considered reliable as they are randomized controlled trials, with most of them being double-blind. On the other hand, the studies conserning the part on disinfection are mostly comparison studies which are considered less reliable. . Moreover, the sample size studied is not sufficiently large, making it less reliable. Among the selected studies, the average sample size is less than 100 (ranging from 21 to 148). Furthermore, the type of samples included is not representative of a standard population. Most of the teeth studied are single-rooted teeth with straight canals and no difficulties. Even in the case of studies involving multi-rooted teeth, they are generally easy to work with, having wide, straight canals without any curvature (2–15,17–21).

Another limitation lies in the heterogeneity of the parameters used in the studies, both with regard to the irrigant, even in the conventional technique (the composition of irrigant used, its concentration, time of use), and we find the same thing when it comes to the lasers used. In fact, in the same technique we can find a different laser with completely different parameters (wavelength, energies, output, time of use (continuous or discontinuous), placement in the canal). This heterogeneity limits the possibility of comparing the data and drawing global conclusions (2–15,17–21).

All these limitations demonstrate the need to establish a standardized protocol for the use of the laser in endodontic treatment. Furthermore, it is crucial to perform further reliable studies with a larger sample size and anatomical diversity of the teeth used. This will allow a better evaluation of the effects and effectiveness of the laser.

7. CONCLUSION

There are several techniques available to enhance disinfection, such as PAD (Photoactivated Disinfection) and PDT (Photodynamic Therapy), which utilize lasers and photosensors to directly target bacteria without irrigation. Another technique is PIPs (Photon-induced Photoacoustic Streaming), which enhances the action of the irrigant used. Additionally, the use of LLLT (Low-Level Laser Therapy) or PBM (Photobiomodulation) also aids in reducing post-treatment pain.

Regarding the analgesic aspect of lasers, there is a consensus that the application of a laser not only provides pain relief to patients but also accelerates the healing process.

On the other hand, while it is widely accepted that lasers possess bactericidal properties and aid in debris removal from the canal, there is insufficient evidence to conclusively demonstrate that lasers can replace conventional techniques. The heterogeneity of parameters used in studies poses a challenge in reaching definitive conclusions.

These findings underscore the crucial need for more reliable and rigorous studies, with standardized procedural methodologies, to address these aspects.

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