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Dissertação conducente ao Grau de Mestre em

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Gandra, 3 de junho de 2020

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Trabalho realizado sob a Orientação de "Prof Doutor Júlio C. M. Souza (PhD,MSC)"e Co-orientação do Prof António Augusto Melo Ferraz (MSC).

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Eu, acima identificado, 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.

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Eu, **"Júlio César Matias de Souza"**, com a categoria profissional de **Professor** do Instituto Universitário de Ciências da Saúde, tendo assumido o papel de Orientador da Dissertação intitulada *"A scoping review on the teeth root canal system disinfection by combining low level laser therapy and ordinary disinfection solutions "*, do Aluno do Mestrado Integrado em Medicina Dentária, **"Sarah Hajjar"**, declaro que sou de parecer favorável para que a Dissertação possa ser deposita para análise do Arguente do Júri nomeado para o efeito para Admissão a provas públicas conducentes à obtenção do Grau de Mestre.

Gandra, 03 de Junho de 2020

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A minha binomia, sempre presente qualquer que seja a situação.

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E aos meus zozianes, presentes desde o primeiro dia, longe de mim, mas sempre no meu coração.

Resumo

O objetivo deste estudo foi realizar uma revisão integrativa sobre o efeito sinérgico da terapia com laser Er:YAG ou Nd:YAG associada a irrigação com soluções convencionais para desinfeção de canais radiculares. Uma busca sistemática da literatura foi realizada na plataforma eletrônica MEDLINE (PubMed), utilizando a combinação dos seguintes termos científicos: endodontic treatment, root canal, intracanal treatment, laser, Er-Yag, Nd-Yag, disinfection, faecalis, decontamination. Os estudos selecionados reportaram um alto efeito anti-bacteriano com eliminação de aproximadamente 98-99% de *E. faecalis* em terapias laser com Er: YAG ou Nd: YAG associada com irrigação com NaOCl. Além disso, o laser Er:YAG promoveu uma desinfeção em profundidade de até 500 µm, através da *smear layer* e no interior dos túbulos dentinários. No entanto, a espessura da dentina e a anatomia dos canais radiculares influenciam a ação da terapia à laser. Além disso, os parâmetros que envolvem intensidade, tempo e modo de terapia laser devem ser ajustados, dependendo das condições anatômicas e da estrutura dos dentes remanescentes. De facto, o uso da terapia laser em baixa intensidade em combinação com métodos de irrigação convencional aumenta consideravelmente o efeito antibacteriano durante o tratamento endodôntico.

PALAVRAS-CHAVE: tratamento endodôntico, canal radicular, tratamento intracanal, laser, Er:YAG, Nd:YAG, desinfeção.

Abstract

The aim of this study was to conduct a scoping review on the synergistic effect of Er:YAG or Nd:YAG laser therapy and ordinary disinfection solutions for tooth root canal disinfection. A systematic literature search was conducted on MEDLINE (PubMed) electronic database using a combination of the following terms: endodontic treatment, root canal, intracanal treatment, laser, Er:YAG, Nd:YAG, disinfection, faecalis, decontamination. The selected studies reported that Er:YAG or Nd:YAG laser treatment combined with NaOCl provide an ultra-high bactericidal effect by 98-99% on the removal of *E. faecalis* biofilms. Additionally, Er:YAG laser promoted a 500 µm depth disinfection though smear layer down into the dentin tubules. Nevertheless, the dentin thickness and the anatomy of the teeth root canal would influence the action of the laser therapy. Also, parameters involving intensity, time, and mode of laser therapy should be adjusted depending on the anatomical conditions and remnant teeth structures. Thus, the use of low laser therapy in combination with ordinary teeth root treatment enhance considerably the antibacterial effect.

KEYWORDS: endodontic treatment, root canal, intracanal treatment, laser, Er:YAG, Nd:YAG, disinfection.

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1. Introduction

The goal of endodontic treatment is to prevent and interrupt pulpal/periradicular diseases leading to the preservation of teeth(1–3). Teeth root canal treatment deals with the removal of bacteria and their toxins from intracanal canal dentin, detin tubules, and contaminated smear layer with bacteria(4). Additionally, the intracanal space can be shaped for filling with retentive post materials for further tooth crown restoration(2,5). The major concern associated with endodontic failure is the persistence of bacteria and debris in the smear layer and dentin tubules after ordinary physicochemical treatment of root canal systems by using only endodontic files and irrigation solutions(2,4,6). On friction and reciprocating wear, root canal instrumentation produces a layer of organic and inorganic material by friction and wear that can cause accumulation of bacteria and their by-products(2,7). Even well instrumented, approximately 35% of the teeth canals surfaces remain untouched(7–10) which leads to potential re-treatment. In case of post-treatment infections, the presence of persistent microorganisms is regularly reported such as *Enterococcus faecalis, Candida spp.*, and *Actinomyces spp* (1,11). *Fusobacterium nucleatum* has been commonly isolated from root canals with periapical lesions(1).

During teeth root canal instrumentation, irrigation solutions are used in association to remove debris from smear layer and microorganisms(12). Also, liquid solutions decrease the friction forces between the endodontic files and intracanal walls(7). Currently, sodium hypochlorite (NaOCl) is the most commonly used and effective irrigant for root canal disinfection(12,13). NaOCl can dissolve organic matter in on the teeth root canal walls and acts by direct contact with the bacteria (3,12). Concerning the anatomic complexities of the teeth root canals , it is still a challenge to eliminate bacteria within the micro-scale regions untouched by the endodontic files, such as in lateral canals (4,9,12). Also, NaOCl has limitations such toxicity and high surface tension which decrease the removal of inorganic components from the smear layer(4).Adverse effects can be clinically noticeable when irrigation solutions are pressed into the periapical tissues (3). In this way, the eradication of bacteria must be enhanced by using physical methods such as laser therapy(14).

Nowadays, laser therapy has been used in many fields of medicine and dentistry due to its safety and effectiveness(1,7). Laser-based procedures can be used at several steps of endodontic treatment involving shaping the teeth root system, detaching broken endodontic files, eradicating bacteria(10). There are different types of laser according to the nature of the active system although Erbium (Er) and Neodymium (Nd) lasers have revealed promising results for clinical applications in teeth root treatment(2,15,16). The Nd:YAG laser emits light in the infrared with a wavelength of 1064 nm through fibers with diameters ranging from 200 up to 600µm(17). In clinical procedures, the intensity has been assessed between 1 and 3 W over a period of 7sec with or without relaxation time(17,18). Nd:YAG light absorption is higher in hemoglobin and melanin which allows light depths from 0.5 up to 4 mm in pigmented or richly vascularized tissues(19). The Er:YAG laser emits radiation with a wavelength of 2940 nm and the intensity and time parameters are similar to those on Nd:YAG procedures(20). Er:YAG laser has very low light penetration and the light is entirely absorbed at the surface of the target tissues resulting in minimum thermal propagation(1,21). A low thermal propagation in association of energy absorption can provide an effective anti-bacterial effect without tissue injuries that is of interest in teeth root canal treatment(19).

Thus, the aim of this study was to conduct a scoping review on the synergistic effect of Er:YAG or Nd:YAG laser therapy and ordinary disinfection solutions for root canal disinfection. It was hypothesized that the combination of low-level laser therapy and ordinary disinfection liquid solutions can enhance the elimination of bacteria species in tooth root canal on endodontic treatment.

2. Method

A literature search was performed on PUBMED (via National Library of Medicine) using the following combination of search terms: "endodontic treatment "OR "root canal" OR "intracanal treatment" AND "laser" OR "Er:YAG" OR "Nd:YAG" AND "Disinfection" OR "decontamination" OR "faecalis . The inclusion criteria involved articles published from January 1995 up to January 2020 reporting decontamination of tooth root canals by a synergistic effect of ordinary disinfection liquid solutions and Er:YAG or Nd:YAG laser therapy.

The eligibility inclusion criteria used for article searches also involved: articles written in English; meta-analyses; randomized controlled trials; and prospective cohort studies. The total of articles was compiled for each combination of key terms and therefore the duplicates were removed using Mendeley citation manager. Three of the authors (JCMS, AF, SH) independently analyzed the titles and abstracts of potentially relevant articles. A preliminary evaluation of the abstracts was carried out to establish whether the articles met the purpose of the study. Selected articles were individually read and evaluated concerning the purpose of this study. The following factors were retrieved for this review: author names, journal, publication year, purpose, type of lasers, laser parameters such as intensity, exposure time, laser type, wavelength, application mode, concentration of irrigation solution and type of bacteria.

3. Results

The literature search on PUBMED identified a total of 131 articles, as seen in Figure 1. A total of 90 duplicates were removed while 6 articles were excluded considering they did not meet the inclusion criteria. Once reading the titles and abstracts of the articles, 9 articles were excluded concerning they did not provide comprehensive data regarding the purpose of the present study. At last, 26 studies were included in this review.

Within the selected studies, 22 (68%) articles investigated the antibacterial effect of the Er-YAG laser, while the other 14 articles (43%) evaluated the antibacterial effect of Nd-YAG laser. Therefore, 21 studies (65%) evaluated the combined effect of lasers and disinfection solutions while 8 articles (25%) assessed the use of laser without combination with any irrigation solution. The retrieved data on the laser parameters, irrigation solutions, and microbiological methods are given in Table 1.

The major findings are drawn as follow:

- Combinations of Er:YAG or Er,Cr:YSGG and NaOCl revealed the strongest antibacterial effect among the tested protocols. The removal proportion of colony forming unit (CFU) varied from 36 up to 89% in the disinfected groups, whereas only 2–5% bacteria were eradicated in the negative control group. The anti-bacterial effects of laser-activated irrigation solutions were more effective than those of the laser-irradiation groups (4). The proportion of bacterial reduction in the treatment groups were reported in the following descending order: Er:YAG/ NaOCl (98.8%), UltraSonique irrigation/ NaOCl (98.6%), NaOCl (94.0%), Er:YAG / Normal Saline (91.9%), UltraSonique/ Normal Saline (78.1%), and Normal Saline (51.1%) ($p<0.05$) (22).
- Er:YAG laser treatment combined with NaOCl irrigation solution showed an ultra-high bactericidal effect on *E. faecalis* biofilms within a 500 mm depth disinfection of dentin tubules (23). Er:YAG laser irradiation at 0.5 W for 30 s combined with NaOCl irrigation was preferable due to the lower emission power and shorter irradiation time. In addition, the use of NaOCl irrigation under Er:YAG laser irradiation at 1.0 W for 20 s reached an effective bacterial reduction of 99.2% (20).

- A ultra-high bacterial eradication of 99.64% was recorded for Er:YAG laser irradiation at 1.5 W during five cycles of 5 s with 20 s breaks in-between, followed by 99.16% bacteria eradication on Nd:YAG laser irradiation at 1.5W for the same parameters (6). A decrease of 5-folds CFU of *A. Oris/S.gordonii* was recorded on Er:YAG laser irradiation at 5W/cm^2 in combination with NaOCl irrigation for 20s using a 600 μm tip(1). Besides the disinfection of canals by using Er:YAG at energy ranging from 10 and 100 mJ, results showed that *E. faecalis* could survive and grow even from small numbers (24).
- Nd:YAG laser irradiation on 1.5 W, 15 Hz, at four sessions of 5 s each resulted in a significant reduction of the *E. faecalis* bacterial, corresponding to a potential eradication at 99.7% (25). Furthermore, an additional study showed that Nd:YAG at 1.5 W laser provided a higher eradication (~98%) when compared to that (77%) for Er,Cr:YSGG for the same parameters. (26). Moreover, the use of the Nd :YAG laser on 1.5 W, 15 Hz, 100 mJ, and pulse fluency of 124 J/cm^2 during a single session of treatments showed a decrease of endotoxins within the root canal. (17)
- Regarding the morphological aspects of teeth root canals, Er:YAG laser showed a higher anti-bacterial effect by 6.4-10.8% on narrow canals and by 1.5-3.1% on curved canals when compared to the Nd:YAG laser (27)
- Laser-activated irrigation treatment utilizing photon-induced photoacoustic streaming (PIPS) can also enhance the disinfection of the teeth root canals as reported in a previous study when the colony forming unit (CFU) decreased from 336 down to 0.27 (14).The findings pointed out that laser-activated irrigation using 5% NaOCl and a modified PIPS protocol resulted in effective eradication of the bacterial biofilm and removal of the contaminated smear layer (9).

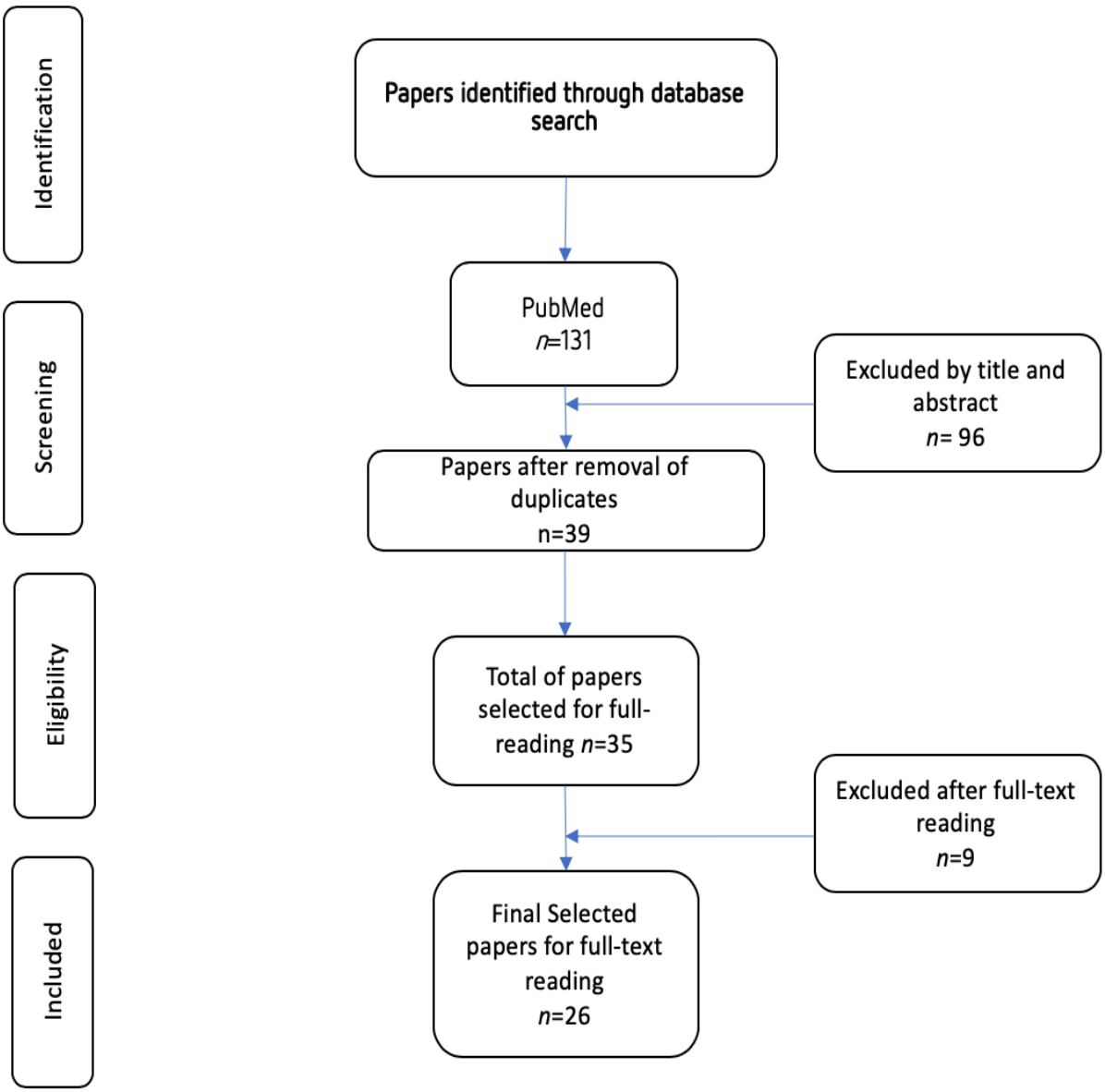

Figure 1. Schematics of the selection of articles.

Table 1. Relevant data gathered from the retrieved studies.

Authors (YEAR)	Purpose	Study design/Bacteria growth conditions and analyses	Laser irradiation parameters	Irrigation solutions	Main Outcomes
Henninger, et al (2019)	Evaluation of the antimicrobial effect of activated irrigation with different modes of Er:YAG laser application on microorganisms related to secondary endodontic infection	*In vitro* Bacterial strains : E. faecalis (ATCC 29212), Streptococcus gordonii (ATCC 10558), Actinomyces oris (MG1), F. nucleatum (ATCC 25586), and Candida albicans (ATCC 76615). Strains were grown on trypticase soy agar (TSA) plates (Oxoid, UK) with 5% of sheep blood for 24 h at 37°C. Microbial counts were expressed as log10 CFU	Laser-activated irrigation (LAI) with 300 mum tips during 20sec, 70 mJ at 5 W/cm2 or 600 mum tips during 20 sec, 30 mJ at 0,5 W/cm2 were tested with or without intermittent irrigatio	0.9% sodium chloride (NaCl) solution	Er:YAG laser activated irrigation with 600 mum tip revealed that when root canals were infected with A. Oris/S.gordonii, there is a CFU reduction of 5log10.
Wang et al (2018)	Comparison of the antibacterial effect for several parameters of laser irradiation against *Enterococcus faecalis* biofilms in dentinal tubules	*In vitro.* 70 single-rooted teeth were rinsed with 5.25% NaOCl and 17% ethylene diamine tetraacetic acid (EDTA) for 4 min in an ultrasonic bath (Sankei Giken Industry Co Ltd., MIE,	Diode laser emitted a wavelength of 980nm, 100mJ, 15 Hz, and 1.5 W ND:YAG, laser at wavelength of 1064 nm, 100 mJ, 15 Hz, and 1.5W. ND : YAP ER, CR:YSGG or	-5.25% sodium hypochlorite (NaOCl) irrigation,	Combinations of Er:YAG/ NaOCl or Er,Cr:YSGG/ NaOCl revealed the highest antibacterial effect among the tested protocols. The proportion of dead cells varied from 36% to 89% in the disinfected groups, whereas only 2–5% of the cells were

		Japan) to remove the smear layer and then immersed in sterile water for 10 min to remove the remnants. All specimens were sterilized by autoclaving (121°C, 15 min) in deionized water. Groups of samples were incubated in brain heart infusion (BHI) at 37°C for 24 h. Then samples were randomly selected and examined by SEM to ensure the presence of E. faecalis, or using a LIVE/DEAD bacterial viability stain and examined by CLSM.	Er:YAG laser irradiation emitted a wavelength of 1340 nm, 300 mJ, 10 Hz, 3 W, and a pulse duration of 150 Is.		dead in the negative control group
Korkut, et al (2018)	Comparison of antibacterial effect and smear layer removal on diode, Er:YAG or Nd:YAG laser irradiation by using photon-induced photoacoustic streaming (PIPS) and ordinary irrigation agent.	*In vitro.* Inoculation of 1st molar root canals with a pool of two field strains and one certified strain (ATCC 29212) of 10^8 CFU mL^{-1} *E. faecalis* into BHI broth and incubated overnight at 37°C. E. faecalis counts and SEM scores were analyzed by one- way analysis of variance using statistical software SPSS	Nd:YAG (1064 nm),diode lasers (940 nm) or Er:YAG laser (2940 nm).	5% NaOCl	Exposure to the Nd:YAG and diode laser irradiations and Er:YAG laser irradiation using PIPS-activated irrigation resulted reductions in the viable counts ranging from 4.77 to 5.24 log

De Meyer, et al (2017)	Evaluation of the antimicrobial effect of laser-activated irrigation (LAI) on biofilms formed in simulated root canals	*In vitro.* The test species were E.faecalis and S.mutans. The bacteria were streaked onto BHI agar plates and cultivated for 24h at 37°C. Prior to each experiment, single colonies were inoculated into BHI broth. Each artificial root canal was inoculated with 1 :1 mixture of both cell suspension.The number of CFU was determined by plate counting and compared across groups (ANOVA, $P \leq 0.05$).	LAI with a 2940 nm Er:YAG laser (20 Hz, 50 mus, 20 or 40 mJ, conical fibre tip at two positions)	Sterile saline and NaOCl (2.5%)	The use of NaOCl resulted in greater biofilm reduction with no significant differences between treatment groups.

Cheng, et al (2017)	Evaluation of the potential of Erbium:Yttrium Aluminum Garnet laser-activated sodium hypochlorite irrigation (Er:YAG + NaOCl) for minimally invasive endodontics	*In vitro* Three hundred thirty-five permanent human teeth with straight root canals and mature apical roots were inoculated with (ATCC 29212) 1.5 mL Enterococcus faecalis suspension [*10^8 colony forming units (CFUs)/mL] at 37°C for 4 weeks. The counting was performed by SEM.	Er:YAG (0.3 W, 20 sec) or Er:YAG at 0.3 W for 40 and 60 sec, or at 0.5 and 1.0 W for 20 sec.	NaoCl	The Er:YAG + NaOCl reached an effective disinfection result. The 15#/Er:YAG + NaOCl with Er:YAG laser irradiation at 1.0 W for 20 sec reached an effective bacterial reduction of 99.2% and may be considered a promising procedure for MIE.
Cheng, et al (2017)	Evaluation of the bactericidal effect of Er:YAG laser-activated sodium hypochlorite irrigation (Er:YAG + NaOCl) on biofilms of Enterococcus faecalis clinical isolate.	*In vitro.* The 18 isolates and C,E.faecalis were inoculated individually into 5mL BHI broth and incubated under anaerobic conditions at 37°C. The root canals were examined using scanning electron microscopy (SEM). The bacterial reductions were evaluated using the cell count method.	Er:YAG laser-activated irrigations, Er:YAG + NS or Er:YAG + NaOCl . The Er:YAG laser was activated at 20 mJ, 25 Hz, 0.5 W at 15-sec intervals every 15 sec.	Normal saline (NS) or NaOCl, ultrasonic activated irrigations US + NS and US + NaOCl	The Er:YAG + NaOCl showed an effective bactericidal effect on biofilms of E. faecalis isolate (98.8%) which may be considered an effective protocol for root canal treatment

Golob et al, (2017)	Determination of the effectiveness of laser-activated irrigation by photon-induced photoacoustic streaming (PIPS) in the reduction of Enterococcus faecalis in root canal disinfection, varying laser energy output, and sodium hypochlorite (NaOCl) concentration	*In vitro.* 83 extracted single-rooted teeth were inoculated with 10uL of vancomycin-resistant E.Faecalis. The specimens were incubated for 4 weeks at 37° and fresh bacterial suspension was provided every 24 hours. The bacterial count was performed using SEM.	Er:YAG laser using a PIPS 600/9 tip at the following parameters: 10 mJ or 20 mJ, 15 Hz, and a 50-microsecond pulse duration at 0.15 W or 0.3 W average power,	NaOCl (1%, 3%, and 5%) activated using the adjusted PIPS protocol)	Laser-activated irrigation using 5% NaOCl and a modified PIPS protocol resulted in effective eradication of the bacterial biofilm and removal of the smear layer.
Kasic, et al (2017)	Comparison of the efficacy of three differents lasers in disinfection of root canals inoculated with Enterococcus faecalis and Candida albicans biofilms	*In vitro.* Suspension for inoculation was prepared by mixing pure cultures of E. faecalis and C. albicans, which were grown on blood agar for 24 h, with 2 mL of saline. Root canals were filled with 10 IL of suspension and incubated at 37°C at 100% humidity for 7 days. After different disinfection protocols, the number of E. faecalis and C. albicans CFUs was determined for each root canal. Results were statistically processed in SPSS	Er:YAG laser (0.3 W) with PIPS, Nd:YAG laser (1.5 W) or Er,Cr:YSGG (1.25 W) laser	Saline	Er,Cr:YSGG laser was the most efficient tool in eradication of E. faecalis and C. albicans biofilms.

Liu et al (2017)	Evaluation of the bactericidal effect of three parameters of Nd:YAP laser-activated irrigation on biofilms of Enterococcus faecalis in root canals.	*In vitro.* E. faecalis frozen bacteria were transformed to BHI agar plate and incubated for 24 h at 37 °C. A 1.5 × 10^8 CFU/mL which equaled 0.5 McFarland was then prepared. 100 µL of the suspension was injected into each canal. The suspension was carried to the entire root canal length using a #15 K-file. The roots were incubated at 37 °C for 2 weeks. Teeth were firstly spilt, and one half examined by scanning electron microscopy (SEM). The other half involved examination of bacterial colonization in dentinal tubules using confocal laser scanning microscopy (CLSM).	Nd:YAP laser (180 mJ) + NaOCl, Nd:YAP laser (280 mJ) + NaOCl or Nd:YAP laser (360 mJ).	In group 1: the roots were treated with syringe irrigation using 5.25% NaOCl (5 mL, 60 s). In group 2: the 5.25% NaOCl was activated by the Nd:YAP laser (Lokki dt, Vienne, France) at 180 mJ, 0.9W. In group 3: the 5.25% NaOCl was activated by the Nd:YAP laser at 280 mJ, 1.4 W. In group 4: the 5.25% NaOCl was activated by the Nd:YAP laser at 360 mJ, 1.8 W.	Bacterial reductions in the treatment groups for dentinal tubules are presented in a descending order as follows: Nd:YAP laser (360 mJ) (53.7%), Nd:YAP laser (280 mJ) (51.5%) > Nd:YAP laser (180 mJ) (45.3%) > 5.25% NaOCl (31.9%) > control (19.3%) ($p < 0.05$). Nd:YAP laser of 280 mJ and 360 mJ showed effective bactericidal effect in removing E. faecalis biofilm from the root canal walls and dentinal tubules
Cheng, et al (2016)	Evaluation of the bactericidal effect of Er:YAG laser radiation combined with sodium	*In vitro.* E.Faecalis was streaked into BHI agar plates and	The Er:YAG laser was activated, respectively, at 0.3, 0.5 and 1.0 W for either 20 or 30 s	52.5 g l (-1) NaOCl and normal saline.	The groups treated with 0.5W for 30s and 1.0 W for 30s showed no bacterial growth

	hypochlorite (NaOCl) irrigation in the treatment of Enterococcus faecalis deep inside dentinal tubules.	cultured for 24h at 37°C. Single colonies were inoculated into BHI and incubated at 37°C for 24H. Root canals before and after treatments were examined using scanning electron microscopy (SEM)			(100 % loss of bacteria) at 300, 400 and 500 mm inside dentinal tubules. This setting was confirmed to be optimal and might be considered as a new alternative to conventional root canal disinfection.
Al Shahrani, et al (2014)	Determination of the effectiveness of laser-activated irrigation by photon-induced photoacoustic streaming (PIPS) using Er:YAG laser energy in decontaminating heavily colonized root canal systems in vitro.	*In vitro.* Growth of E.Faecalis was maintained by weekly subculturing in trypticase soy agar plates then incubated at 37°C for 72h then inoculated into BHI. One milliliter of BHI containing 10^8 E.faecalis was delivered into the prepared root canal. The entire tooth specimen was submerged into the BHI broth and all samples were kept at 37° for 3 weeks. The CFUs after 24h was observed and counted. Other samples were analyzed by SEM, remaining samples were analyzed by CLM.	PIPS settings were all preset to 50 musec pulse, 20 mJ, 15 Hz, for an average power of 0.3 W.	PIPS+6% NaOCl, PIPS+saline and 6% NaOCl.	The use of the PIPS system along with NaOCl showed the most efficient eradication of the bacterial biofilm. Indeed, we can see a CFU counts of 0.27 CFU, whereas in the control group there is a count of 336 CFU. It appears that laser-activated irrigation (LAI) utilizing PIPS may enhance the disinfection of the root canal system.

Sahar-Helft, et al (2013)	Evaluation of the mineral content and surface morphology of root canals coated with Enterococcus faecalis biofilm after treatment with several endodontic irrigation solutions, with and without Er:YAG laser-activated irrigation (LAI).	*In vitro.* The split teeth were sterilized in an autoclave for 20 min at 121°C. They were incubated in brain heart infusion broth (BHIB) for 48 h. After sterilization, the split teeth were exposed to E. faecalis for 3 weeks at 37°C. At the end of the incubation period, the two halves of each split root were put back together in the dental impression material to recreate the configuration of the original root canal. The samples were examined by SEM.	Er-YAG laser 500 mJ at a frequency of 12 Hz for four cycles of 15 sec each, giving a total of 60 sec irradiation.	Solutions tested were 2% chlorhexidine and 17% ethylenediaminetetraacetic acid (EDTA) and saline.	17% EDTA irrigant solution combined with Er:YAG laser showed the best results for removing bacteria from the root canal walls. In vitro irrigation solutions, combined with Er:YAG laser irradiation, were effective in removing E. faecalis biofilm from root canal walls.
Meire et al (2012)	Evaluation of different wavelength and irradiation intensity required for microbial inactivation.	*In vitro.* Cultures were maintained on solid growth media at 4°C and subcultured regularly. Prior to each experiment, cultures were grown in the respective liquid medium and incubated overnight at 37°C. P. acnes was cultured under anaerobic conditions using the Anaerocult A Mini system (Merck). TITs (total inhibition threshold) were	Er:YAG laser was operated in single-pulse mode. Pulse energies of 40–400 mJ and pulse lengths of 100, 300, 600, and 1,000 μs were tested. - Nd:YAG laser was operated with pulse trains because single pulses were ineffective. Output power was 15 W and frequency was 100 Hz.	None	For the Er:YAG laser, TITs (total inhibition threshold) ranged from 100 and 210 mJ, and differed significantly between species and pulse lengths. On Nd:YAG irradiation, TITs were around 5,300 J/cm2 for *C. albicans* and 7,100 J/cm2 for *P. acnes*. No inhibition was recorded for *E. faecalis*. Er:YAG irradiation was more effective than Nd:YAG in inactivating microorganisms on agar medium.

		determined for every species and pulse length.			
Archilla, et al (2012)	Analyzing if a single session of Nd :YAG laser irradiation would be able to neutralize endotoxin within the human dental root canal.	*In vitro.* The upper chamber water was aspired, and the root canals were dried with sterile paper point. Then 500uL of a solution containing endotoxin from E. coli were placed in the upper chamber. The passage of the endotoxin through the dental root dentin was observed for 72h.	Nd:YAG laser (1.5 W, 15 Hz, 100 mJ and pulse fluency of 124 J/cm2)	None	The endotoxin concentration in the negative control group was significantly lower than that of the positive control group (endotoxin content = 0,0070 for the negative group vs 0,0450 in the positive one). A single session of intracanal Nd:YAG laser irradiation is able to neutralize endotoxin in the dental root tissues.
Meire et al (2012)	Comparison of the antimicrobial efficacy of two-high power lasers (Nd:YAG and Er:YAG) and two commercial antimicrobial photodynamic therapy (aPDT) systems with that of sodium hypochlorite (NaOCl) action on Enterococcus faecalis biofilms grown on dentine discs.	*In vitro.* E.Faecalis was inoculated into tryptic soy broth (TSB)and grown overnight at 37°c. Surviving bacteria were har- vested, and the number of CFU per disc was determined by plate counting.	Er:YAG laser irradiation (2940 nm, 50 mJ or 100 mJ, 15 Hz, 40s), and Nd:YAG laser irradiation (1064 nm, 2 W, 15 Hz, 40 s)	NaOCl (2.5%).	Complete eradication was seen with the 2.5% NaOCl (1 min) treatment for 4/9 samples (44%) and with the Er:YAG (100 mJ) treat- ment for 1/13 samples (8%)
Rahimi, et al (2012)	Evaluation of the bactericidal effects of Nd:YAG laser on biofilm of Enterococcus faecalis.	*In vitro.* Each tooth was placed in a sterile microtube containing 2 mL of a	3-W laser beam for 10 sec. A fiber tip with a diameter of 200 lm was used to deliver a 3 W beam of Nd:YAG laser (LAMBDA	1% sodium hypochlorite solution using 21 gauge 5mL syringes.	The bacterial counts in groups 2 and 4 had decreased to 54% and 2.39% of the control group, respectively. The effect

		standard suspension of E. faecalis (ATCC 29212). To prepare the standard suspension, at first a pure culture of the microorganism was provided by incubating the bacteria at 37°C for 24 h in the presence of 10% CO_2. Then the young bacteria were cultured in the BHI broth and the microbial concentration was adjusted to the standard 0.5 MacFarland solution (10^8 cells/mL) using a UV VISIBLE spectrophotometer at an optical density (OD) of 1 at 600 nm. The procedure continued for 6 weeks, during which the teeth were incubated at 37°C. The colony-forming unit (CFU) counting technique was used to determine remaining bacterial counts.	S.P.A, Brendola, Italy) into the root canals; the laser beam had a wavelength of 1064 nm, an energy of 120 mJ, and a frequency of 25Hz. The total irradiation time was 10sec for each canal.		of Nd:YAG laser beam on E. faecalis biofilm is less than that of sodium hypochlorite solution. A combination of laser and sodium hypochlorite results in complete elimination of E. faecalis biofilm.
Dos Santos Antonio, et al (2012)	Assess bacterial reduction after intracanal irradiation with the Er:YAG laser.	*In vitro.* The canals were inoculated with 10 µl of a suspension containing approximately 1.5×10^8 CFU/ml of E. faecalis (ATCC 29212) using	The canals were irradiated with the Er:YAG laser using two energy settings: 60 mJ and 15 Hz, and 100 mJ and 10 Hz.	1% NaOCl, irrigated with 17% EDTA, and then washed with physiological solution activated by ultrasound.	With 60 mJ and 15 Hz there was an immediate reduction of 99.73% and the reduction was 77.02% after 48 h, and with 100 mJ and 10 Hz there was an immediate reduction of 99.95%

		a micropipette. The roots were then incubated at 37°C for 72 h. The remaining bacterias were counted using CFU.			and the reduction was 84.52% after 48 h. Although the best results were observed with 100 mJ of energy, the difference between the two settings was not statistically significant. The count performed 48 h after irradiation showed that E. faecalis were able to survive and can grow even from small numbers.
Cheng, et al (2012)	Evaluation of the bactericidal effect of Nd:YAG, Er:YAG, Er,Cr:YSGG laser radiation, and antimicrobial photodynamic therapy (aPDT) in experimentally infected root canals compared with standard endodontic treatment of 5.25% NaClO irrigation.	*In vitro.* E. faecalis (ATCC 4083) taken from its frozen stock was streaked onto brain heart infusion agar plates and cultured for 24 hours at 378C. Single colonies were inoculated into BHI broth and incubated at 378C for 24 hours. The cell suspension was adjusted spectrophotometrically to ensure that the amount of bacteria was approximately 10^8 cells/ml. The morphology of bacterial cells before and after treat-ment was examined by scanning electron microscopy (SEM).	Nd:YAG, Er:YAG (Er:YAG/NaClO/NS/DW), (Er:YAG/NS/DW), Er,Cr:YSGG, and aPDT	5.25% NaClO + 0.9% normal saline + distilled water or 0.9% normal saline + distilled water	All the laser radiation protocols tested, especially Er:YAG/NaClO/NS/DW, have effective bactericidal effect in experimentally infected root canals. Er:YAG/NaClO/NS/DW seems to be an ideal protocol for root canal disinfection during endodontic therapy

Franzen, et al (2011)	Determination of the bactericidal effect of laser irradiation in dentine of various depths at a wavelength of 1,064 nm and pulse durations of 15 and 25 ms.	90 dentine slices were cut from bovine incisors and divided into two groups (45 slices each) of thickness 500 and 1,000 μm. All were inoculated with a suspension of Enterococcus faecalis (5.07×10^9 bacteria/ ml). After irradiation, the colony-forming units (CFU) were counted and evaluated.	Nd :YAG laser with the following parameters : 1.75 W, 0.7 Hz for 4s.	None	The results of this in vitro study showed that Nd:YAG laser irradiation with a pulse duration of 15 ms eliminated an average of 49% and 29% of E. faecalis at dentine depths of 500 mum and 1,000 mum, respectively, and irradiation with a pulse duration of 25 ms eliminated 70% (500 mum) and 50% (1,000 mum).
Yasuda, et al (2010)	Evaluation of the bactericidal efficacy of Nd:YAG and Er:YAG laser in the experimentally infected curved root canals.	*In vitro.* A pure bacterial culture of gram+ E.faecalis was used. The bacterial sample was thawed and incubated for 24h on BHI agar plate at 37°C under aerobic conditions. The E.Faecalis culture was calibrated to 1.0x10^ 8 CFU/mL spectrophotometrically in BHI broth.	Laser irradiation at each of the two settings, 50 mJ, 10 pps (0.5 W) or 100 mJ, 10 pps (1.0 W)	None.	In the straight root canals, the Er:YAG laser showed higher bactericidal effects by 6.4-10.8% than did the Nd:YAG laser. Conversely, the bactericidal effect of Er:YAG laser in the curved root canals was higher by 1.5-3.1% than was that with the Nd:YAG laser. The bactericidal effect of the Er:YAG laser in the curved root canal is significantly lower than that in the straight root canal ($p < 0.05$)
Wang, et al (2007)	Evaluation of the bactericidal effect of the Er,Cr:YSGG laser and the Nd:YAG laser in	*In vitro.* E.Faecalis was cultured for 24 hours at 37° in BHI. Each	Er,Cr:YSGG laser at 1 W and 1.5 W and Nd:YAG 1 W and at 1.5 W.	None.	The Er,Cr:YSGG laser gave a reduction of 77% after irradiation at 1 W and 96% at

	experimentally infected root canals.	of the specimens was incubated in anaerobic conditions. After incubation, the number of the CFUs was counted.			1.5 W. The Nd:YAG laser gave a reduction of 97% at 1W and 98% at 1.5W. Compared with the Er,Cr:YSGG laser, the Nd:YAG laser is more effective.
Vezzani, et al (2006)	Evaluation of the degree of disinfection of the Er:YAG laser in root canals.	*In vitro.* 46 permanent maxillary canine single straight roots were used for this study. 5 microorganisms were evaluated; Bacillus subtillis, E.faecalis, Pseudomonas aeruginosa, S.Aureus e C.Albicans. The strains were inoculated in 5mL of BHI and then incubated at 37° for 24h. After 24 h of incubation, the colony-forming units (CFUs) were counted	Er:YAG laser at 100 mJ, varying the frequency (7, 10, and 16 Hz).	1.0% and 2.5% NaOCl solution.	There was a microbial reduction of 85.33% for the group irradiated with Er:YAG laser at 100 mJ/7 Hz, 74.58% at 100 mJ/10 Hz, and 89.50% at 100 mJ/16 Hz. For the groups irrigated with 1.0% and 2.5% NaOCl solution, 83.15% and 84.46% values of microbial reduction were obtained respectively.
Bergmans, et al (2006)	Define the role of Nd:YAG lasers in root canal disinfection along with a minimally invasive treatment concept.	*In vitro.* A bacterial suspension of E.faecalis and standardized (4x10^8 CFU mL-1) in BHI broth was inoculated into 6 of the prepared root canals using sterile syringes. The samples were incubated for two days under anaerobic conditions at 37°C.	Nd:YAG laser irradiation : 1.5 W, 15 Hz, four times for 5s	None	The teeth that received no laser treatment (positive control) showed a number of CFU mL^1 of $6.8 \cdot 10^6$ ($3.0 \cdot 10^6 – 6.9 \cdot 10^6$), whilst bacteria were found in all cases. Nd:YAG laser irradiation (1.5 W, 15 Hz, four times for 5 s)

		Resultant CFUs counts were associated with observations of bacterial cell structural changes using SEM.			resulted in a significant reduction of the E. faecalis bacterial of CFU $mL^{)1}$ of $2.3 \cdot 10^4$ ($1.2 \cdot 10^4$–$3.0 \cdot 10^4$), meaning a potential disinfection (99.7% kill) but no sterilization .
Dostalova et al (2002)	Examination of the ability of Er:YAG laser radiation using a movable waveguide.	*In vitro.* Before treatment (as soon as the teeth were opened) and after treatment (before canal filling), the CFU were counted to determine 21 various microorganisms. The content of the root canal was removed via irrigation with 0.2 mL of sterile RTF transport medium, which was inserted into 3 mL of BHI The samples were incubated for 24 h at 37°C, and the sterile brain–heart infusion under the same conditions was inoculated as a control.	Er:YAG laser at the wavelength of 2.94 mm, maximum generated energy 0.6 J, duration of the generated pulses around 250 msec, and the maximum repetition rate 6 Hz.	5.25% solution of sodium hypochlorite.	Classical enlargement and shaping of the root canal is effective in 60%. Application of calcium hydroxide prepares sterile root canal in 80%. Er:YAG laser irradiation via movable waveguide (energy of 100 mJ, 30 pulses, repetition rate 4 Hz) can ensure residual disinfection of the root canal.
Moritz, et al (1999)	Comparison of the antibacterial effectiveness of the Nd:YAG, the Ho:YAG, and the Er:YAG laser in infected root canals	*In vitro.* After sterilization by steam autoclave for 10min at 134°C, each root canal was	Nd :YAG, Ho :YAH and Er :YAG lasers at standardized power settings 1.5W.	None	At 1.5 W, the best results were obtained by the Er:YAG laser achieving a mean bacterial elimination of 99.64%,

		inoculated with a standard volume of 10uL of E.Coli and E.faecalis. The teeth were incubated for 48 hours at 37°C and the count were performed by CFU.			followed by the Nd:YAG laser (99.16%), and the Ho:YAG laser (99.05%).
Klinke at al (1997)	Examination of the anti-bacterial effects of Nd:YAG laser irradiation in the depth of the root canal dentin	*In vitro*. The tests were carried out on dentine slices (100 and 1000 µm) which were sterilized and inoculated on one side in a medium containing 4uL *Streptococcus mutans.* After 40min incubation under anaerobic conditions the CFU were counted for the entire plate.	Nd:YAG laser at a setting of 1.5 W, 15 pps with a 200 µm glass fiber from an angle of about 5°. The radiation was carried out under constant movement and irradiation	None	A high signification eradication of bacteria was recorded for both thickness of slices when compared to the untreated slices.

4. Discussion

4.1. Ordinary teeth root canal treatment

Bacteria are the main etiological agents of infectious pulpal and periapical diseases. Even though a low number of remnant bacteria into root intracanal surfaces can initiate a gradual proliferation and bacteria accumulation over time(1,8,24). The prevalence of *E. faecalis* in persistent infections ranges from 24% up to 77%(23) due to their bacteria capability to withstand long periods of nutrient limitation in root canals as a single species. *E. faecalis* penetrate into the smear layer and dentin tubules to depths between 160 and 1000 um leading to a biofilm formation on the root apex surfaces(4,15). Bacteria biofilms are 1000 times more resistant to antibacterial agents than planktonic bacteria that justify the clinical limitations for bacterial eradication. (11,15) Therefore, the ultimate goal of endodontic treatment is to avoid microbial contamination in complex root canal anatomy, mainly in the apical third(28).

Ordinary teeth root canal treatment combines instrument-based preparation with antiseptic irrigating solutions(28) that comprises several procedures and types of irrigation solutions.(7) The use of irrigation solutions is the only way to promote the disinfection of those areas of the root canal which were not treated by physical instrumentation(12).In fact, the physical instrumentation can remove bacteria, contaminated smear layer, and debris by friction and wear pathways supported by the chemical and flowing effect of the irrigation procedure(29). Irrigation also allows lubrication of the endodontic tools (files), that enables cleaning and maintains their cutting efficiency(12).A effective chemical effect must combine: good antibacterial efficacy, solvent action on organic debris, and biocompatibility in the root canal apex. (12) However, the mechanical movement and chemical effect of the irrigation solutions also promote the degradation of the endodontic files. (7)

The most common irrigation solution used is sodium hypochlorite (NaOCl) since it has been known for its antibacterial action, proteolytic effect, dissolution capability of necrotic tissue and debris, and low cost(3). Nevertheless, it is recommended to use low concentration are recommended ranging between 2% and 5.5% to avoid toxicity. On the treatment, the solution should be frequently refreshed and kept in motion by agitation or continuous irrigation to enhance the effectiveness. Then, the speed of tissue dissolution can be

increased with effective agitation and refreshment.(12) However, the major drawbacks revealed by the use of NaOCl solutions are the potential toxicity into the periapical region as well as the lack of entire eradiation of bacteria at micro-canals or thick smear layer (7),(12).

The use of chelating agents in association with NaOCl, such as particular ethylenediamine tetraacetic acid (EDTA), is common among practitioners aiming to remove the contaminated smear layer.(30) (13) EDTA does not affect organic tissue, which becomes more biocompatible although it has limited antibacterial effect due to the chelation of metal cations from the outer bacteria membrane(3).EDTA activity deals directly with the elimination of smear layer and dentin debris. Such effect is dependent on time, concentration (at around 17%), and pH. (7) Thus, EDTA can improve the antibacterial effect of disinfecting agents in thick smear layers due to its capability to increase the permeability of dentine(12).

Conventional irrigation with syringes has been a widely endodontic procedure before the advent of passive ultrasonic activation. That consists by dispensing of an irrigation solution into a root canal through needles/cannulas of variable gauges, either passively or under agitation. The latter is achieved by moving the needle up and down in the teeth root canal space(31). However, it does not guarantee a complete renewal of the irrigation solution in the apical zone. The persistence of a gas bubble (vapor lock) in the apical zone decrease the penetration of the irrigation solution leading to an accumulation of bacteria and debris (31)

4.2. Laser in teeth root intracanal treatment

In teeth root treatment, several types of lasers have been used as follow: Nd:YAG, Nd:YAP, Er:YAG, Er, Cr:YSGG. (4,18,32) Neodymium: YAG laser emit light with wavelength at 1064 nm in the near infrared range of the electromagnetic spectrum of light(19).The light from the Nd:YAG laser penetrates deeper into the soft tissue (down to 5 mm)(33) and it is selectively absorbed by hemoglobin, oxyhemoglobin, and melanin(19,34).

Therefore, Nd:YAG is often used in dentistry to vaporization and incision of the soft tissue in surgical procedures. In endodontics, Nd:YAG laser currently represent one of the methods

of root intracanal decontamination because of their ability to propagate through the dentin tubules up to 1 mm, as seen in Figure (2). The photothermal effects from the Nd:YAG parameters also showed high efficiency to disturbing the bacteria viability (Figure 2). The Nd:YAG laser energy can be emitted in pulsed mode in which each pulse begins and ends naturally at determined time points in a Gaussian progression(15,18). The interval between each pulse allows a thermal relaxation time for the cooling down of the soft tissue and to control the thermal effects(17). The Nd: YAG laser light can be absorbed by bacterial pigments (*E. coli*), while non-pigmented bacteria (like *E.faecalis*) were shown to be translucent to near-infrared wavelength (1064 nm). Thus, the bactericidal effect of Nd:YAG laser on non- pigmented bacteria occurs by heating of the environment surrounding bacteria such as in the root intracanal regions(35) (32). In a previous study, Nd:YAG laser was capable to eradicate *E. faecalis* and *C. albicans* in the root canal space(35).

Regarding Nd:YAG laser parameters, cycles of 3 J/s for 15 s followed by a 15-s recovery interval can be continued for prolonged periods without risk of thermal damage to surrounding tissues(26,34,36). The anti-bacterial percentage of the Nd:YAG laser has been reported in the range from 77 up to 86% at 10Hz, 1.5W for 15 s, 97% to 99% at 200 mJ for 20 s, and >99% at 1.5 W for 5 s(27,34). Pulsed Nd:YAG laser irradiation at 1.5 W over four cycles of 5s cause a bacterial reduction of 98% (25,26). Other studies showed Nd:YAG laser irradiation with a pulse duration of 15 ms eradicated 49% and 29% *E. faecalis* in dentine tubules' depths of 500 µm and 1 mm, respectively. An increase in the pulse irradiation duration to 25 ms eradicated 70% and 50% *E. faecalis* in dentine tubules' depths of 500 µm and 1 mm, respectively (15). However, laser irradiation only performs the desired antibacterial effect in combination with the irrigation solution (11).

Erbium-based lasers provide a light in the medium infrared range that is mainly absorbed by the outer layers of the soft tissue, from 100 to 300 µm. In endodontics, the wavelength is at the absorption maximum range of hydroxyapatite and water, with minimal thermal side effects and an anti-biofilm effect at low energy(1,8).

Additionally, light can propagate into the dentin tubules up to 400 µm depth (Figure 2)(19,23).Erbium lasers works with an integrated water sprayer with dual cleaning and cooling functions(1).That supports the application in root intracanal treatment(1,37) . Er:YAG

laser irradiation using PIPS-activated irrigation has been shown to induce a series of rapid and powerful photoacoustic shockwaves, capable of forcefully propelling the irrigating solution throughout the entire root canal system(9,35,38). Also, such system can remove the smear layer within the canals(18,20,26). Several studies showed an improvement of the bacterial eradication by using Er:YAG laser treatment in combination with irrigating solutions(13,14,18). Er:YAG laser parameters at 1.5 W over five cycles of 5s with 20 s relaxation time revealed an ultra-high bacterial eradication of 99.64%(6) *E. faecalis* in root canal and also within dentin tubules with 500 mm depth (1,39).

4.3. Optimal conditions for bacteria eradication.

On the accomplishment of endodontic treatment with high effectiveness, several laser protocols have been developed to remove the smear layer and to enhance the disinfection in root canals(16,24,40). Laser systems are efficient methods of decontamination considering the elimination of bacteria by the combination of parameters and photothermal effects. The highest levels of bacteria eradication (~99.2%) were noticed for the Er:YAG laser at 1.0 W for 20 sec super-short pulse with 50usec interval that results in an energy at 20mJ/cm^2 (20). The Er: YAG can also be used at 0.5 W irradiation for 15s intervals to reach 98.8% bacterial elimination(23). Er:YAG laser irradiation (2940 nm wavelength) by using PIPS cause a colony forming unit (CFU) reduction ranging from 4.77 up to 5.24 log(2). Regarding the tips for disinfection, 600 µm tips showed higher levels of bacteria eradication than the 300 µm tips since CFU decreased at 5log10(1). Concerning the Nd-YAG laser, studies revealed a proper bacteria removal at 1.5W, 280 mJ, and 360 mJ (32). The concentration of endotoxin decreased from 0.0450 down to 0.0070 after only one session of Nd:YAG laser irradiation at 100 mJ(17). Results showed that Nd: YAG laser should be operated with pulse mode instead of single one.

A mean removal rate of *E. faecalis* from 49% (500 µm dentin depths) to 29% (1mm) was recorded on pulse of 15 ms and at 1.75 W, 0.7 Hz over a period of 4s. Nd-YAG laser irradiation with a pulse of 25 ms eliminated 70% (500 µm dentin depths) and 50% *E. faecalis* (500 µm dentin depths)(15). The different types of lasers used above can activate the irrigation solution by a shock wave phenomenon leading cell lysis and mechanical breakup of smear layer. That provide the penetration of the irrigation solution into the deeper dentin

layers(9,38). The elimination of smear layer establishes the interface between the filling material and the root canal surfaces(26). The use of Er :YAG lasers has been shown *in vitro* to be more effective than conventional (syringe-based) irrigation in terms of removal of smear layer removal in the apical part of the canal(8). The Er:YAG laser in association with a double irradiation of 17% EDTA and 25% NaOCl has been demonstrated to be the most effective method in removing smear layer, and showed a reduction of more than half bacteria present, even in the apical third which is described as the critical region during endodontic treatment(41)(13).

The use of the laser in synergy with the irrigation solutions has showed a greater efficiency than the use of the laser alone. A combination of 2.5% hypochlorite during 1min in association with the Er-YAG laser at 100 mJ results in complete elimination of *E. faecalis* biofilm (18) (11). The use of NaOCl at a concentration of 5% shows a significant reduction in bacteria when used with Nd: YAG or Er: YAG laser. The proportions of dead bacteria vary between 36 and 89% in the treated groups and only from 2 to 5% in the untreated groups(2,4,9). NaOCl activated by PIPS was the most effective method for removing E. faecalis biofilm in the root canal system when compared with the other irrigation techniques tested. This method both mechanically and chemically debrides and decontaminates the root canal system using Er:YAG laser energy at subablative power levels with a short 50Isec pulse duration at 15Hz and 0.3W of power(14).

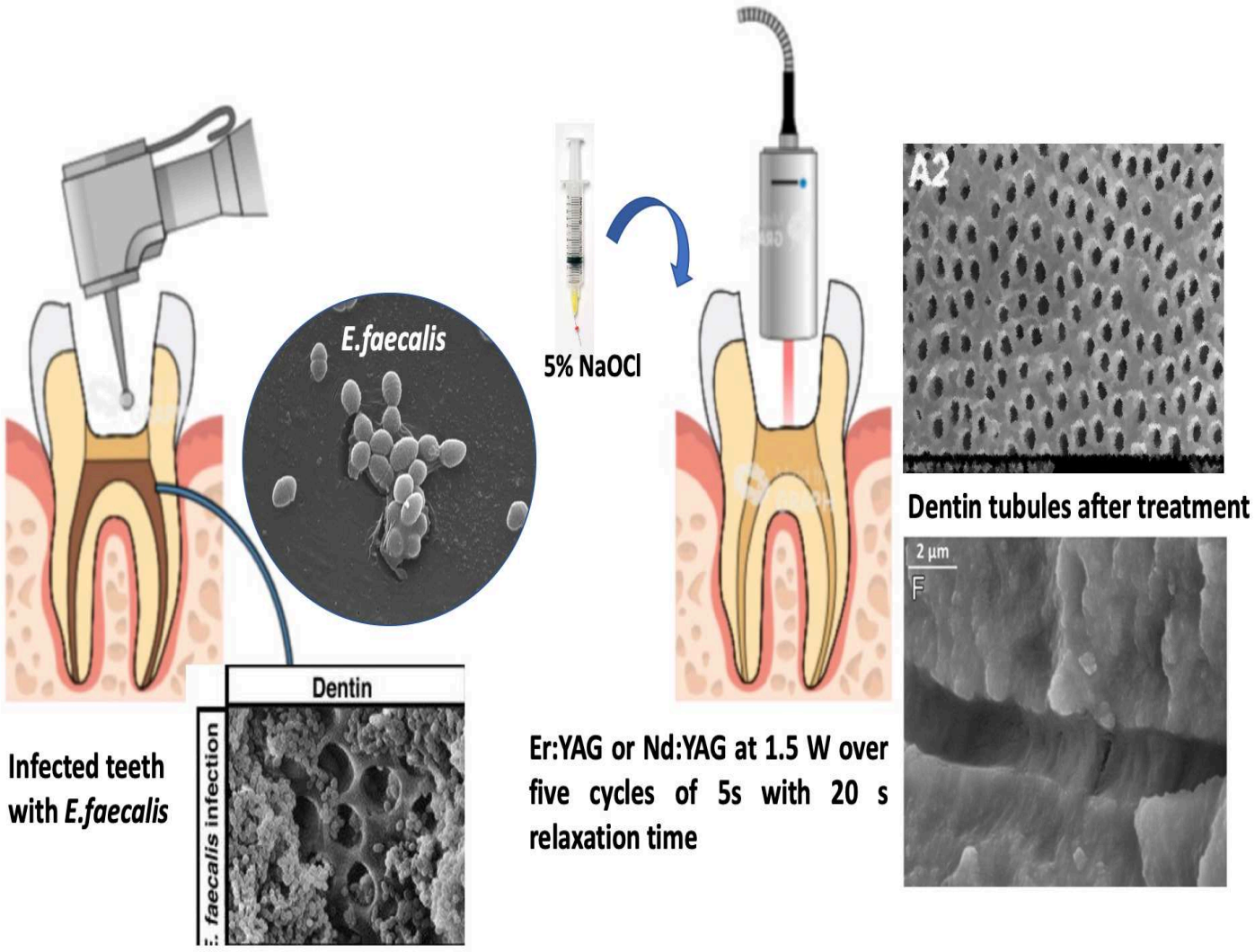

Figure 2. Schematics of teeth root canal treatment and removal of bacteria.

5.Conclusions

In the present review, significant findings from selected articles supported the synergistic effect of Er:YAG or Nd:YAG therapy and ordinary disinfection solutions for tooth root canal treatment. The main concluding remarks from the previous studies can be drawn as follow:

- The use of irrigation solution is not effective for completely eradicate bacteria inside the root canals. The morphological aspects of teeth root canals play an important role in the bacteria eradication. Thus, a thick contaminated smear layer can accumulate bacteria in micro-regions such as dentin tubules, and canal ramifications;
- The use of Er:YAG laser showed the highest percentage (99.6%) of bacteria removal followed by Nd:YAG laser (98%). Additionally, Er:YAG laser treatment combined with NaOCl showed an ultra-high antibacterial effect on *E. faecalis* biofilms within a further 500 mm depth disinfection of dentin tubules;
- Taking into consideration a low emission power and shorter irradiation time, the most effective synergistic procedure involved a Er:YAG laser irradiation at 1.5 W during five cycles of 5 s and 20 s breaks in-between combined with NaOCl irrigation;
- Future studies should evaluate the combination of effective laser irradiation protocols and alternative natural compounds since NaOCl can induce inflammatory reactions at the teeth root apex. Also, solutions containing bioactive compounds might enhance the tissue healing and increase the long-term success of the endodontic treatment.

References

1. Henninger E, Berto LA, Eick S, Lussi A, Neuhaus KW. In Vitro Effect of Er:YAG Laser on Different Single and Mixed Microorganisms Being Associated with Endodontic Infections. Photobiomodulation, photomedicine, laser Surg. 2019 Jun;37(6):369–75.

2. Korkut E, Torlak E, Gezgin O, Ozer H, Sener Y. Antibacterial and Smear Layer Removal Efficacy of Er:YAG Laser Irradiation by Photon-Induced Photoacoustic Streaming in Primary Molar Root Canals: A Preliminary Study. Photomed Laser Surg. 2018 Sep;36(9):480–6.

3. Plotino G, Cortese T, Grande NM, Leonardi DP, Di Giorgio G, Testarelli L, et al. New Technologies to Improve Root Canal Disinfection. Braz Dent J. 2016;27(1):3–8.

4. Wang X, Cheng X, Liu X, Wang Z, Wang J, Guo C, et al. Bactericidal Effect of Various Laser Irradiation Systems on Enterococcus faecalis Biofilms in Dentinal Tubules: A Confocal Laser Scanning Microscopy Study. Photomed Laser Surg. 2018 Sep;36(9):472–9.

5. Pecora JD, Brugnera-Junior A, Cussioli AL, Zanin F, Silva R. Evaluation of dentin root canal permeability after instrumentation and Er:YAG laser application. Lasers Surg Med. 2000;26(3):277–81.

6. Moritz A, Schoop U, Goharkhay K, Jakolitsch S, Kluger W, Wernisch J, et al. The bactericidal effect of Nd:YAG, Ho:YAG, and Er:YAG laser irradiation in the root canal: an in vitro comparison. J Clin Laser Med Surg. 1999;17(4):161–4.

7. Chubb DWR. A review of the prognostic value of irrigation on root canal treatment success. Aust Endod J. 2019;45(1):5–11.

8. De Meyer S, Meire MA, Coenye T, De Moor RJG. Effect of laser-activated irrigation on biofilms in artificial root canals. Int Endod J. 2017 May;50(5):472–9.

9. Golob BS, Olivi G, Vrabec M, El Feghali R, Parker S, Benedicenti S. Efficacy of Photon-induced Photoacoustic Streaming in the Reduction of Enterococcus faecalis within the Root Canal: Different Settings and Different Sodium Hypochlorite

Concentrations. J Endod. 2017 Oct;43(10):1730–5.

10. Stabholz A, Sahar-Helft S, Moshonov J. Lasers in endodontics. Dent Clin North Am. 2004;48(4):809–32.

11. Rahimi S, Shahi S, Gholizadeh S, Shakouie S, Rikhtegaran S, Soroush Barhaghi MH, et al. Bactericidal effects of Nd:YAG laser irradiation and sodium hypochlorite solution on Enterococcus faecalis biofilm. Photomed Laser Surg. 2012 Nov;30(11):637–41.

12. Haapasalo M, Shen Y, Wang Z, Gao Y. Irrigation in endodontics. Br Dent J. 2014 Mar;216(6):299–303.

13. Sahar-Helft S, Stabholtz A, Moshonov J, Gutkin V, Redenski I, Steinberg D. Effect of Er:YAG laser-activated irrigation solution on Enterococcus Faecalis biofilm in an ex-vivo root canal model. Photomed Laser Surg. 2013 Jul;31(7):334–41.

14. Al Shahrani M, DiVito E, Hughes C V, Nathanson D, Huang GT-J. Enhanced removal of Enterococcus faecalis biofilms in the root canal using sodium hypochlorite plus photon-induced photoacoustic streaming: an in vitro study. Photomed Laser Surg. 2014 May;32(5):260–6.

15. Franzen R, Gutknecht N, Falken S, Heussen N, Meister J. Bactericidal effect of a Nd:YAG laser on Enterococcus faecalis at pulse durations of 15 and 25 ms in dentine depths of 500 and 1,000 mum. Lasers Med Sci. 2011 Jan;26(1):95–101.

16. Sadik B, Arikan S, Belduz N, Yasa Y, Karasoy D, Cehreli M. Effects of laser treatment on endodontic pathogen Enterococcus faecalis: a systematic review. Photomed Laser Surg. 2013 May;31(5):192–200.

17. Archilla JRF, Moreira MSNA, Miyagi SPH, Bombana AC, Gutknecht N, Marques MM. Single session of Nd:YAG laser intracanal irradiation neutralizes endotoxin in dental root dentin. J Biomed Opt. 2012 Nov;17(11):118002.

18. Meire MA, Coenye T, Nelis HJ, De Moor RJG. In vitro inactivation of endodontic pathogens with Nd:YAG and Er:YAG lasers. Lasers Med Sci. 2012 Jul;27(4):695–701.

19. Juric IB, Anic I. The Use of Lasers in Disinfection and Cleanliness of Root Canals: a

Review. Acta Stomatol Croat. 2014 Mar;48(1):6–15.

20. Cheng X, Tian T, Tian Y, Xiang D, Qiu J, Liu X, et al. Erbium:Yttrium Aluminum Garnet Laser-Activated Sodium Hypochlorite Irrigation: A Promising Procedure for Minimally Invasive Endodontics. Photomed Laser Surg. 2017 Dec;35(12):695–701.

21. Vezzani MS, Pietro R, Silva-Sousa YT, Brugnera-Junior A, Sousa-Neto MD. Disinfection of root canals using Er:YAG laser at different frequencies. Photomed Laser Surg. 2006 Aug;24(4):499–502.

22. Cheng X, Xiang D, He W, Qiu J, Han B, Yu Q, et al. Bactericidal Effect of Er:YAG Laser-Activated Sodium Hypochlorite Irrigation Against Biofilms of Enterococcus faecalis Isolate from Canal of Root-Filled Teeth with Periapical Lesions. Photomed Laser Surg. 2017 Jul;35(7):386–92.

23. 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. J Med Microbiol. 2016 Feb;65(2):176–87.

24. Dos Santos Antonio MP, Moura-Netto C, Camargo SEA, Davidowicz H, Marques MM, Maranhao de Moura AA. Bactericidal effects of two parameters of Er:YAG laser intracanal irradiation: ex-vivo study. Lasers Med Sci. 2012 Nov;27(6):1165–8.

25. Bergmans L, Moisiadis P, Teughels W, Van Meerbeek B, Quirynen M, Lambrechts P. Bactericidal effect of Nd:YAG laser irradiation on some endodontic pathogens ex vivo. Int Endod J. 2006 Jul;39(7):547–57.

26. Wang Q-Q, Zhang C-F, Yin X-Z. Evaluation of the bactericidal effect of Er,Cr:YSGG, and Nd:YAG lasers in experimentally infected root canals. J Endod. 2007 Jul;33(7):830–2.

27. Yasuda Y, Kawamorita T, Yamaguchi H, Saito T. Bactericidal effect of Nd:YAG and Er:YAG lasers in experimentally infected curved root canals. Photomed Laser Surg. 2010 Oct;28 Suppl 2:S75-8.

28. Caron G, Nham K, Bronnec F, Machtou P. Effectiveness of different final irrigant activation protocols on smear layer removal in curved canals. J Endod. 2010

Aug;36(8):1361–6.

29. Yilmaz M, Yılmaz S, Dumanı A, Kuden C, Yoldas O. Effects of seven different irrigation techniques on debris and the smear layer: a scanning electron microscopy study. Niger J Clin Pract. 2017 Mar;20(3):328–34.

30. Hartmann RC, Neuvald L, Barth VJ, de Figueiredo JAP, de Oliveira SD, Scarparo RK, et al. Antimicrobial efficacy of 0.5% peracetic acid and EDTA with passive ultrasonic or manual agitation in an Enterococcus faecalis biofilm model. Aust Endod J J Aust Soc Endodontology Inc. 2019 Apr;45(1):57–63.

31. Gu L, Kim JR, Ling J, Choi KK, Pashley DH, Tay FR. Review of contemporary irrigant agitation techniques and devices. J Endod. 2009 Jun;35(6):791–804.

32. Liu T, Huang Z, Ju Y, Tang X. Bactericidal efficacy of three parameters of Nd:YAP laser irradiation against Enterococcus faecalis compared with NaOCl irrigation. Lasers Med Sci. 2019 Mar;34(2):359–66.

33. Moshonov J, Orstavik D, Yamauchi S, Pettiette M, Trope M. Nd:YAG laser irradiation in root canal disinfection. Endod Dent Traumatol. 1995 Oct;11(5):220–4.

34. Ramskold LO, Fong CD, Stromberg T. Thermal effects and antibacterial properties of energy levels required to sterilize stained root canals with an Nd:YAG laser. J Endod. 1997 Feb;23(2):96–100.

35. Kasic S, Knezovic M, Beader N, Gabric D, Malcic Al, Baraba A. Efficacy of Three Different Lasers on Eradication of Enterococcus faecalis and Candida albicans Biofilms in Root Canal System. Photomed Laser Surg. 2017 Jul;35(7):372–7.

36. Klinke T, Klimm W, Gutknecht N. Antibacterial effects of Nd:YAG laser irradiation within root canal dentin. J Clin Laser Med Surg. 1997 Feb;15(1):29–31.

37. Meire MA, Coenye T, Nelis HJ, De Moor RJG. Evaluation of Nd:YAG and Er:YAG irradiation, antibacterial photodynamic therapy and sodium hypochlorite treatment on Enterococcus faecalis biofilms. Int Endod J. 2012 May;45(5):482–91.

38. Wang X, Cheng X, Liu B, Liu X, Yu Q, He W. Effect of Laser-Activated Irrigations on Smear Layer Removal from the Root Canal Wall. Photomed Laser Surg. 2017

Dec;35(12):688–94.

39. Cheng X, Guan S, Lu H, Zhao C, Chen X, Li N, et al. Evaluation of the bactericidal effect of Nd:YAG, Er:YAG, Er,Cr:YSGG laser radiation, and antimicrobial photodynamic therapy (aPDT) in experimentally infected root canals. Lasers Surg Med. 2012 Dec;44(10):824–31.

40. Dostalova T, Jelinkova H, Housova D, Sulc J, Nemec M, Duskova J, et al. Endodontic treatment with application of Er:YAG laser waveguide radiation disinfection. J Clin Laser Med Surg. 2002 Jun;20(3):135–9.

41. Guidotti R, Merigo E, Fornaini C, Rocca J-P, Medioni E, Vescovi P. Er:YAG 2,940-nm laser fiber in endodontic treatment: a help in removing smear layer. Lasers Med Sci. 2014 Jan;29(1):69–75.