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Review Article

Er,Cr: YSGG Laser with Various Firing Tips: Its Magic Wand in Endodontics. Review

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Abstract

The outcome of root canal treatment is based on efficient disinfection of the root canal system and prevention of reinfection. Current chemomechanical cleaning methods do not always achieve these goals, and insufficient root canal disinfection is the main reason for endodontic failure. Due to high energy content and specific characteristics of laser light, laser treatment has been proposed for cleaning and disinfecting the root canal system. This paper reviews the literature covering the effect of Er:YAG, Er,Cr:YSGG, Nd:YAG laser on the root canal wall in the removal of smear layer and against intracanal bacteria.

Recently, the use of laser energy to induce cavitation and acoustic streaming of intracanal irrigants using different laser tips has been investigated. Based on recent literature, it can be concluded that lasers have bactericidal effects and can remove smear layer effectively. However, they still cannot replace either EDTA or sodium hypochlorite and should be considered as an adjunct to the current chemical root canal disinfection protocols. Certain lasers can help in removing the smear layer and debris and can modify the morphology of the root canal wall. Unfortunately, there have not been enough randomized clinical studies evaluating endodontic treatment outcome following the use of laser.

Keywords: *Endodontics; Root Canal; Er,Cr:YSGG Laser; Fiber Tips; Disinfection; Smear Layer; Ethylene Diamine Tetraacetic Acid (EDTA); Sodium Hypochlorite; Bond Strength; Surface Treatment; Composite Core; Fiber Post; Zirconia Post*

Introduction

Total elimination of bacteria from infected root canal systems remains the most important objective of endodontic therapy. Biomechanical instrumentation of the root canal system has been suggested to achieve this task. However, because of the complexity of the root canal system, it has been shown that the complete elimination of debris and achievement of a sterile root canal system is still an ongoing challenge. Cleaning and disinfecting a root canal system containing microorganisms gathered in a biofilm is very difficult task because this biofilm has the ability to prevent the entry and action of such disinfecting agents [1].

The modern dentistry and its minimally invasive concepts are supported by the development of innovative materials and advanced techniques [2]. In order to develop new and effective means for treating dental soft and hard tissue diseases, pioneering investigations of the interactions between the energy of the ruby laser with tooth structure were reported in mid-1960 [3,4]. The laser has been widely used in many specialties of dentistry [5-7] and there is ongoing trend to substitute for high-speed handpiece [8,9]. This is because it is safe, reduces pain and providing comfort of patients, significantly reducing noise and vibrations, and disinfect surgical field in comparison with traditional drills [10-12].

The use of lasers in the field of endodontology represents an innovative approach to match these requirements. In general, dental lasers provide greater accessibility of formerly unreachable parts of the tubular network, due to their better penetration into dentinal tissues. The ability of lasers to remove smear layer and debris from the root canal wall and to open up the orifices of dentinal tubules can be exploited for disinfection of the root canal systems [1].

The first use of laser in endodontics was reported by Weichman and Johnson in 1971 [13] who attempted to seal the apical foramen *in vitro* with a high power carbon dioxide (CO_2) laser. Since then, many papers on laser use in endodontics have been published [14]. However, the clinical application of lasers in endodontics started in the late 90s when the new delivery systems, including thin and flexible fibres and endodontic tips, were developed. Today, lasers can be used in various endodontic procedures such as: pulp capping/pulpotomy, cleaning and disinfecting the root canal system, obturation, endodontic retreatment, and apical surgery [15].

Ideal root canal treatment includes the removal of this smear layer [16] that is formed on the dentinal walls during root canal preparation [17] and consists of organic and inorganic particles of dentin, remnants of pulp tissue, microorganisms, endotoxins, and blood cells [18]. Presence of smear layer inhibits penetration of antimicrobial irrigants and medications into dentinal tubules, increases microleakage, and prevents sealer from adhering to dentinal walls [19]. EDTA is commonly used to remove the smear layer because of its capacity to act as a calcium chelating agent [20].

The laser wavelengths described for cleaning and disinfecting the root canal system are: erbium: yttrium aluminium garnet (Er:YAG), 2940 nm; erbium, chromium: yttrium scandium galium garnet (Er,Cr:YSGG), 2780 nm neodimium:yttrium aluminium garnet (Nd:YAG), 1064 nm; diode, 635 to 980 nm; potassium titanyl phosphate (KTP), 532 nm; canals depends on the absorption of their wavelengths in biological components and chromophores such as water, apatite minerals, and various pigmented substances (microorganisms) (Figure 1) [21,22]. Wavelengths of the visible and near-infrared electromagnetic radiation (Nd:YAG, diode, KTP lasers) are poorly absorbed in water and hydroxyapatite and have deeper bactericidal effects in dentine. On the contrary, mid-infrared erbium lasers, whose wavelengths are highly absorbed in water and hydroxyapatite, have a superficial effect on dentine walls and can be used for removal of the smear layer and disruption of intracanal biofilms [23].

The aim of this review article is to highlight the use of Er,Cr:YSGG laser with various firing tips especially the innovative radial firing tip (RFPT 5-14 tip) in endodontic treatment.

The mechanism of action of Er,Cr:YSGG laser during endodontic treatment

The mechanism of action of these erbium lasers is photoablation where laser energy causes photodissociation or breaking of the molecular bonds in tissue (Figure 2). The active laser medium of Er:YAG once stimulated emits a wavelength of 2.94 μm, corresponding to the maximum absorption peak of water and hydroxyl radicals present in dental tissue (Figure 1) [24,25]. The Er,Cr:YSGG laser emits photons at a wavelength of 2.78 μm and is strongly absorbed by water and hydroxyapatite (Figure 1) [26-30], the main components of the dentin [27-31]. The produced energy by erbium lasers, when absorbed by the water in hard and soft dental tissues, is used to cause rapid vaporization and to create microexplosions in these tissue [32-34].

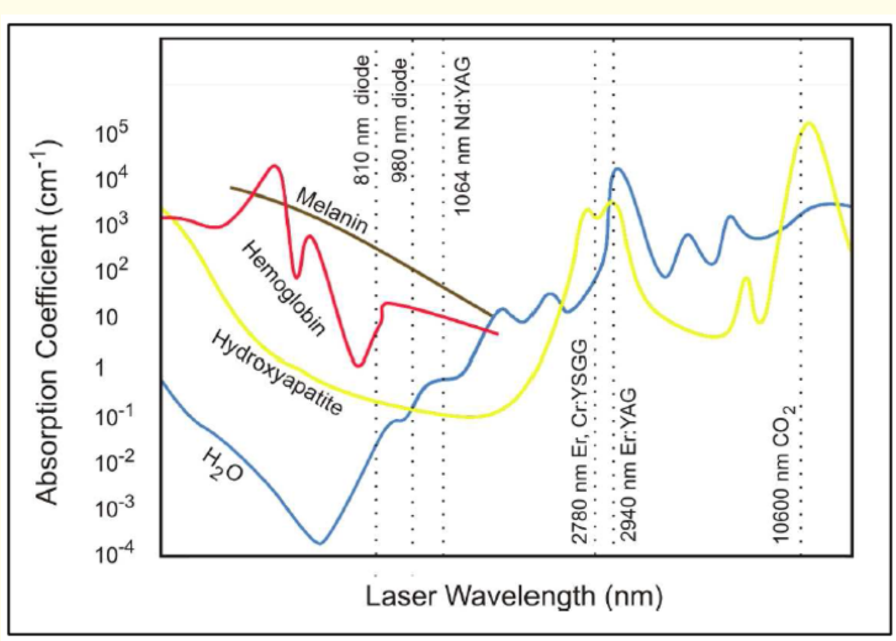

Figure 1: *Absorption coefficients of various dental tissue chromophores relative to laser wavelength.*

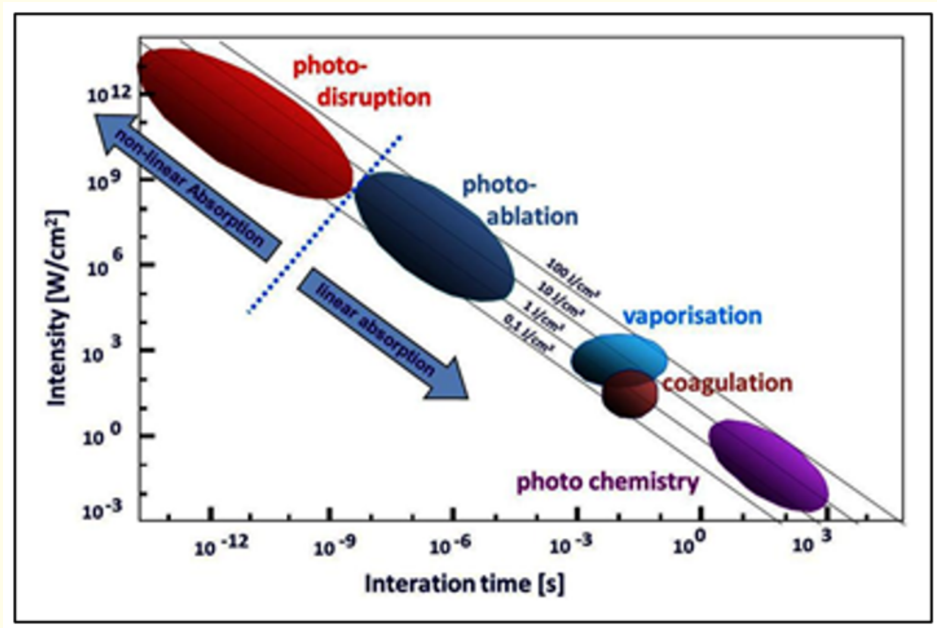

Figure 2: *Map of laser–tissue interactions. The circles give only a rough estimate of the associated laser parameters.*

It has been shown that bacteria colonize the periluminal dentine up to a depth of 1,100 μm [35]. Chemical disinfectants penetrate only 100 μm into the dentine [36]. In addition, curved root canals or lateral canals can be a hinderance in the endodontic treatment. The use of lasers helps to combat this problem. The high penetration depth of the laser beam in the dentinal tissue seems to be the best explanation of the satisfying bactericidal effect of different laser wavelengths. The laser radiation may be transmitted through quartz optical fibers, a property that could facilitate introducing laser light around canal curvatures and irregularities [37]. Laser light can propagate through enamel prisms and dentin tubules acting as optical fibers [38]. The monochromatic, coherent, and directional characteristics of laser light, and the fact that direct contact between target and fiber tip is not required, raise the possibilitythat emission of laser energy could provide a means to disinfect areas deep within the dentin [39,40].

Limitations of lasers in endodontics how they are solved

When using lasers inside the root canal, several limitations have to be taken into consideration. Firstly, the laser light is emitted in a straight line from the tip of an optical plain-ended fibre or a laser guide with a divergence angle of only 18 to 20 degrees [41]. With such unidirectional laser beam, it is difficult to gain equal irradiation of the whole root canal dentine surface [41,42]. Moreover, the root canal preparation as well as retreatment procedures with laser and plain fibres is dangerous in curved root canals because of the risk of creating ledges and perforations [43,44].

To improve the surface area of the root canal dentine being irradiated, a helicoidal withdrawing motion from apical to coronal part is proposed when using fibre tips [45]. Besides, new conical side-firing fibre tips (Figure 3C) are attached to Er,Cr:YSGG laser handpiece (Figure 3A) with 80% lateral and 20% forward radiation provide complete coverage of intra-canal walls [46]. Another limitation is the safe use of lasers in the root canal, especially thermal damage of periradicular tissues through the open apical foramen may occur when using the erbium lasers at ablative settings [47].

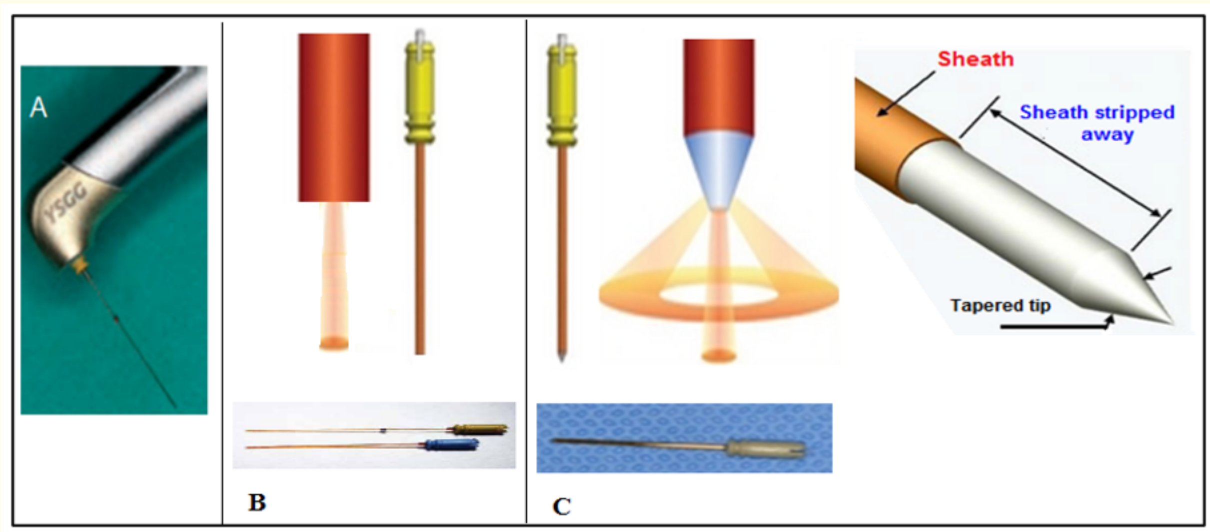

Figure 3: *A) Er,Cr:YSGG hand piece, B) end-firing with frontal emission (axial irradiation) at the end of the tip, and C) radial firing fiber "radial and stripped" terminals (axial irradiation plus radial irradiation).*

Techniques in endodontic laser

Lasers have been used with different techniques in endodontics: 1) Fibers, positioned into the canal, 1 mm shorter than the working length, irradiating while withdrawing the fiber from the canal (Figure 4A), 2) Photo-activated disinfection (PAD), photodynamic therapy, or light-activated disinfection (LAD) requires the use of different photosensitizers with antimicrobial activity that are selectively activated by different wavelengths, and 3) Laser-activated irrigation (LAI) the fibers, positioned into the canal, 5 mm short of the apex (Figure 4B) and photon initiated photoacoustic streaming (PIPS) involves the use of radial-firing tips [48].

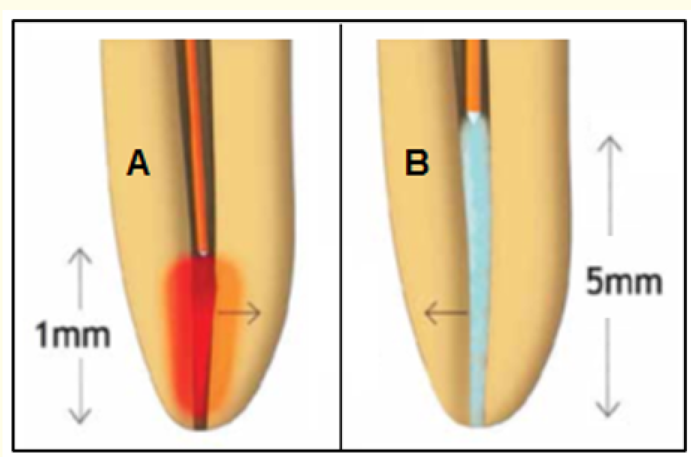

Figure 4: *Position of the laser fibers A) in the traditional laser endodontic technique: 1 mm short of the apex, and B) in the PIPS or LAI: 5 mm short of the apex.*

Types of endodontic fiber tips used with Er,Cr:YSGG laser

Two types of fiber tips are available on the market: a regular one (axial irradiation) and a side firing tip (radial irradiation). Both fiber tips are flexible, reaching the working length in curved canals in all areas of bacterial contamination. Er,Cr:YSGG laser (Figure 3A) with "end-firing" tips (Figure 3B), with frontal emission at the end of the tip, have little lateral penetration of the dentinal wall, so that a radial-emitting tip was proposed in 2007 for the Er,Cr:YSGG laser (Figure 3C) [49,50]. The axial fiber tip is indicated for general hard- and soft-tissue applications, suitable for root canal preparation, enlargement, debridement, and cleaning. Most of its photons direct forward.

The radial firing fiber tips (RFTs) are indicated for access, cleaning, shaping, and disinfection after endodontic instrumentation. Due to their high numeric aperture, photons are more likely to irradiate the lateral dentine tubules, besides irradiating the apical region, potentially increasing the adhesion strength inside all canal areas [51]. They are flexible (12 mm in length, 300 to 400μm in diameter and with "radial and stripped" terminals) and their final 3 mm are without coating (Figure 3C) to allow a greater lateral emission of energy compared with the frontal tip. This mode of energy emission makes better use of the laser energy when, at subablative levels and produces powerful "shock waves" in the irrigants, leading to a demonstrable and significant mechanical effect removing smear layer because of the dramatic cavitation effects they produce on canal walls [52]. This tip has a new and special shape (60 degree cone angle) as it allows firing 360∘ to an irradiation cone as well as straight at the same time. It produces primarily radial emission (80%) of laser energy with a portion of straight emission (20%) [53,54]. Studies have shown that these tips are not hazardous to periapical tissues [55] and improve the light irradiation inside root canals [13,52]. The application of an Er,Cr:YSGG laser with radial firing tips has brought about many advantages in root canal treatment, such as uniform coverage of root canal walls during irradiation [39,53].

Studies done about Er,Cr:YSGG laser use n endodontics

Root canal disinfection

A novel laser activation irrigation system, photon-initiated photoacoustic streaming (PIPS), is used with Er:YAG laser. Having a radial, stripped novel tip (Figure 5A and 5B) in this system PIPS differs from other techniques in that the tip is placed in the pulp chamber (Figure 5C) and kept stable without advancing into the canal orifice indicated that PIPS improves canal cleanliness with a greater number of open tubules compared to nonactivation irrigation [56]. Investigations on laser-activated irrigation reported that pulsed erbium lasers can generate a movement of fluids at high speed through a cavitation effect. The expansion (via thermal effect) and successive vapor bubble implosion within irrigant fluids generate a secondary cavitation effect on the intracanal fluids [57,58]. The pulsed erbium lasers' effect on the irrigants within the root canal produced a clean and debrided dentin surface [59,60].

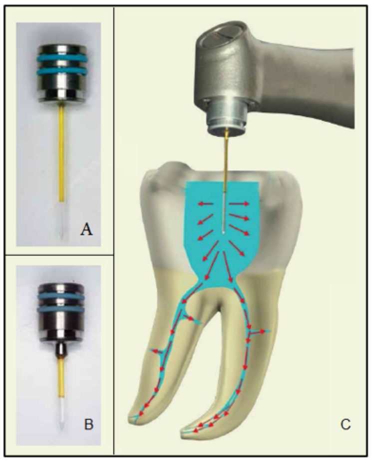

Figure 5: *A) PIPS 400/12 tip B) PIPS 600/9 tips, and C) Position of the laser tip in the PIPS technique: steady in the pulp chamber.*

A particular type of laser activation of irrigants by photo-activated disinfection (PAD) or LAI, utilizes very low energy (ranging from 50 mJ to 20 mJ) at 10 to 15 Hz delivered with very short pulses (50 microseconds) to generate a more profound shock wave than cavitation. The final effect improves canal cleanliness with a greater number of open tubules compared to nonactivation irrigation [55,61,62]. When PIPS is used to activate 17% EDTA, a superior removal of smear layer and debris is obtained when compared to hand irrigation [55,61]. When PIPS is used to activate 6% sodium hypochlorite, an effective bacterial reduction in the endodontic system through a three-dimensional streaming of fluids is obtained [62,63].

There is consensus that laser irradiation has the potential to kill microorganisms and to remove debris and smear layer from root canals. In root canal disinfection, there is insufficient evidence to suggest that any specific laser is superior to the traditional endodontic treatment. Erbium and Nd:YAG wavelengths can be used for the root canal debridement and cleaning; the Erbium lasers for the laser activated irrigation and photon initiated photoacoustic streaming, and the Nd:YAG laser for the evaporation and contraction of the smear layer. Finally, the use of laser is recommended not as an alternative to NaOCl but as an adjunct to the traditional disinfection and debridement protocols. More clinical randomized studies are necessary to evaluate endodontic treatment outcome following the use of laser [64].

A study evaluated the bactericidal effect of the Er,Cr:YSGG laser in straight root canals that were inoculated with E faecalis for 3 weeks and found that there is a reduction in bacteria of 77% after irradiation at 1W, and a reduction of 96% after irradiation at 1.5 W [65]. Another study found that the disinfecting effect of Er,Cr:YSGG laser in root dentin samples was dependent on the output power but was not specific for the bacterial species investigated [66]. Investigating the ability of an Er,Cr:YSGG laser with radial emitting tips to disinfect dentin infected with Enterococcus faecalis found that bacterial recovery decreased when laser irradiation duration or power increased [49].

Another study evaluated Er,Cr:YSGG laser with radial-firing tips in root canal treatment and revealed a decisive disinfectant effect, the smear layer was homogeneously removed from the root canal walls, and temperature elevation at the root surface during irradiation was moderate. This laser is absorbed by dentin owing to the presence of hydroxide and interstitial water (dentin matrix and intratubular). On the basis of the fact that each laser pulse is composed of approximately 150 micropulses and each micropulse is responsible for the penetration of this energy of about 3 μm into water, depending on fluence, it is possible to achieve expansion of intratubular water and the collapse of water vapor as deep as 1,000 μm or more. This effect, known as "micropulse-induced sequential absorption," with expansion and collapse of water vapor, is capable of producing acoustic waves strong enough to disrupt intratubular bacteria [50].

An article described the successful management of a case of lower anteriors with large periapical pathology. Er,Cr:YSGG laser was used as an adjunct to conventional root canal preparation that resulted in remarkable and faster healing of the periradicular lesion in lower anteriors. In this case, significant bactericidal effect and disinfection of the root canals were achieved using Er,Cr:YSGG laser, that resulted in substantial healing in a short period of time. The large periapical lesion present was hence dealt with nonsurgical management, which was otherwise deemed for surgical intervention. The laser energy emitted from the Er,Cr:YSGG laser is highly absorbed by water in tissue and micro-organisms, resulting in instantaneous photo-ablation. In addition, the resulting micro-pulse expansion and collapse of intratubular water produce acoustic waves sufficiently strong to disrupt and kill intratubular bacteria. This effect is most effective in a dry mode, as the laser energy is not absorbed by the water spray and can exert its full effect on the bacteria [1].

The wavelength of Er,Cr:YSGG (2790 nm) is well absorbed in water and hydroxyapatite and is therefore mostly used for the ablation of dental hard and soft tissues. In endodontics it is very effective in the removal of the intra-canal smear layer and have the potential to destroy biofilms on dentine walls [67,68]. Its energy is almost completely absorbed in the first 300 to 400 μm of dentine tissue so that the bactericidal effect is superficial [23,69].

Smear layer removal

Over the last few years, there has been an increasing interest in the use of Er,Cr:YSGG lasers for the agitation of intracanal water-based fluids. Laser activated irrigation (LAI) is based on the creation of specific cavitation phenomena and acoustic streaming in intracanal fluids as a result of photothermal and photomechanical effects. The strong absorption of Er,Cr:YSGG laser energy (at low settings of 50 - 75 mJ) in water and NaOCl causes vaporization and formation of large elliptical vapour bubbles. The vapour bubbles cause a volumetric expansion of up to 1,600 times the original volume of an irrigant with high intracanal pressure which drives the fluid out of the canal. The bubbles implode after 100 to 200 microseconds, creating pressure which sucks fluid back into the canal: inducing secondary cavitation effect [58,60], technique was demonstrated to be effective in the removal of intracanal dentine debris and smear layer [70]. De Moor., *et al.* [57] and De Groot., *et al.* [60] showed a higher efficiency of LAI with Er,Cr:YSGG and 2.5% NaOCl in the removal of dentine debris from the apical part of the root canal compared to conventional irrigation.

If the Er,Cr:YSGG laser is used at low settings (20 mJ, 15 Hz) and ultra-short laser pulses (50 µs), intracanal cavitations and shockwaves are created as a result of photoacoustic and photomechanical effects. This phenomenon is called photon induced photoacoustic streaming (PIPS). Compared to the LAI, where intracanal conical side firing fibre tips are positioned 5 mm from the apex (Figure 4B), PIPS uses a tapered 600 µm wide side-firing stripped tip which is kept at the entrance of the root canal and used with continuous irrigation (Figure 5C) [55]. There is consensus that laser irradiation has the potential to kill microorganisms and to remove debris and smear layer from root canals. In root canal disinfection, there is insufficient evidence to suggest that any specific laser is superior to the traditional endodontic treatment. Erbium wavelength can be used for the root canal debridement and cleaning; the Er,Cr:YSGG lser for the laser activated irrigation and photon initiated photoacoustic streaming, and for the evaporation and contraction of the smear layer [64].

Recent miscellaneous use of Er; Cr; YSGG laser in endodontics

In an *in-vitro* assessment of surface treatment effect of fiber posts with Er,Cr:YSGG laser on their bond to composite core with and without thermocycling by all its limitations, revealed that irradiation of Er,Cr:YSGG laser with 1W power effectively enhanced the bond strength of fiber posts to composite core, and thermocycling slightly (but not significantly) decreased the bond strength at the post-core interface [71].

A comparative assessment of quality of sealing of root canals, subjected to a standard method of processing, processing by the laser and processing by LAI equipment, with sealer and the gutta-percha was performed. Root canal treatments were processed according to the traditional protocol using as an irrigant 3% NaOCl and 17% EDTA solution, LAI equipment, the Er; Cr; YSGG laser 2780 nm at a power 1W and 1,5W and sealed up using single protocol by means of an epoxy siler of AH+ and gutta-percha by continuous wave by means of the CalamusDual (DentsplayMaillefer) device. SEM was used to study the efficiency of sealing depending on a type of processing. The highest sealing of the obturation material to the canal walls was revealed in teeth processed by the laser at a power of 1.5 W confirmed by lack of emptiness between a material and a dentine. Conventional irrigation protocol did not result in an optimal obturation with the extent of empty spaces up to 13 microns. The results of the pilot research are the basis for more extensive studies [72].

Evaluation of the antibacterial effectiveness of sodium hypochlorite (NaOCl) at low concentrations activated by the Er,Cr:YSGG laser-activated irrigation (LAI) against 10-day-old intracanal Enterococcus faecalis biofilm formed inside the root canals concluded that Er,Cr:YSGG LAI proved to be able to improve the intracanal distribution of 0.5% NaOCl after 60 s of activation, reaching the same level of effectiveness than 2.5% NaOCl. This is regarded as of clinical interest, since working with lower concentrations may contribute to reduce undesired effects [73].

The effect of surface treatment of quartz fiber posts with different powers and motion directions of Er,Cr: YSGG laser on their pull-out bond strength to root dentin in endodontically treated premolar teeth was assessed the occlusions were fiber posts treated with 0.5, 1.0 and 1.5 W Er,Cr: YSGG laser showed higher bond strength to dentin compared to posts with no surface treatment. However, the motion directions of laser irradiation had no significant effect on the bond strength. In order to minimize damage to post surface and achieving maximum bond strength, longitudinal surface treatment of posts with 1.0 W power of Er, Cr: YSGG laser is recommended [74].

Conclusion

The use of Er, Cr: YSGG laser is recommended not as an alternative to the traditional disinfection and debridement protocols but as an adjunct to them. More clinical randomized studies are necessary to evaluate endodontic treatment outcome following the use of Er, Cr: YSGG laser

Disclosure Statement

The authors have no financial interest in the materials or devices reviewed and declare no conflict of interest.

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