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REVIEW ARTICLE

Erbium lasers in operative dentistry—a literature review

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Abstract

Introduction Hard tissue modification and cavity preparation addressing the carious lesions of the teeth is the heart of operative dentistry. It is now more than three decades that lasers have been tested and used in caries removal. Twenty-eight years after the first laser construction by Theodore Maiman in 1960, the actual mechanism of thermo-mechanical ablation has been described, and the introduction of erbium lasers in operative dentistry was a reality. A big number of researchers and institutes worldwide have been experimenting the possibilities, limitations, and possible advantages of erbium family lasers (i.e., Er,Cr:YSGG 2790 nm and Er:YAG 2940 nm).

Purpose The aim of this literature review is to summarize evidence-based studies that have been published, trying to clarify the aspects that have been covered so far and simultaneously revealing the parts that need to be tested in future studies.

Materials and methods A systematic bibliographic analysis has been the basis of this literature review on erbium family lasers. The total number of articles that have been screened for this review is 1474.

Conclusions Erbium family lasers have shown their great benefits in different fields of operative dentistry, including painless cavity preparation and caries removal, enamel and dentine modification for bonding and smear layer elimination with respect to pulp tissue. The difference in the parameters of each laser system and the infinite combinations of laser settings that can be selected have led to some contradictive results, which have confused both researchers and clinical dentists. With this review, we try to shed light to the fields that future researchers should focus on.

Keywords Erbium lasers · Operative dentistry · Pain perception

Introduction

With this literature review, we will try to explore the various possibilities of achieving dental hard tissue ablation and the current state-of-the-art procedures used in dentistry with lasers. A description regarding two main wavelengths suitable for this purpose will be given in this chapter, along with their comparison to conventional mechanical caries removal methods.

Biophysical background

The interaction between laser and tissue is strongly dependent on the optical properties of the tissue. Therefore, a study of enamel and dentin composition is necessary in order to find the most suitable laser wavelengths. Enamel is a highly mineralized tissue, composed of 85% mineral, 12% water, and 3% organic material in volume [1]. Dentin has a significantly higher content in organic material (33%), water (20%), and only 47% mineral in volume. The mineral content is formed by carbonated hydroxyapatite crystals organized in enamel rods that are approximately 5 μm in diameter [2]. The occurrence of caries directly affects the mineral and water content in these tissues. As mineral is lost, its volume is replaced by water and organic material. In caries-affected dentin, the water content has an average of 27% in volume, but can reach up to more than 54% depending on the stage of the disease [3].

The erbium laser wavelengths (2.94 and 2.79 μm) are strongly absorbed by water and mineral; at 2.94 μm, there is a strong absorption in water (800 cm^{-1}) while the 2.79-μm wavelength is coincident with a narrow hydroxyapatite absorption band (400 cm^{-1}).

Ablation mechanisms

Dental hard tissue removal can be achieved by two mechanisms: explosive (water-mediated) ablation and explosive vaporization [4].

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The explosive water-mediated thermo-mechanical ablation is the process that occurs with wavelengths between 2.7 and 3 μm and leads to ejection of mineral particles with preserved mineral structure.

Pain perception and patient acceptance

Since the FDA cleared Er:YAG and Er,Cr:YSGG lasers to be used for caries removal and cavity preparation, several clinical in vivo studies have been conducted in order to verify pain perception and patient acceptance of laser treatment.

All of the clinical studies reviewed agreed that the patients' acceptance of laser caries removal is greater than the traditional mechanical removal with a bur. Despite the fact that these studies were conducted in different parts of the world, in all of them, the percentage of the population that preferred the laser treatment was above 70%. The percentage that felt very little or no pain was above 80% [5–9].

Patients generally feel safe and relaxed when a laser is used for any dental treatment, and they describe their experience with laser treatment as a positive one with less discomfort [10].

Surface roughness, conditioning, microleakage, bond strength

There are parameters which indeed lead to high bond strength in irradiated surfaces similar to the bur-prepared cavities, without the need for subsequent acid etching of enamel [11, 12].

It was noted that the pulse duration, with or without acid etching, had an influence on the microtensile bond strength of laser-irradiated enamel and dentin surfaces. Bond strength was observed to decrease with the use of longer pulses without acid etching and increase with the use of short pulses with additional acid etching (comparable to conventional method) [13].

An investigative study was performed to observe the adhesion properties of various currently used bonding systems and enamel surface treatment with an Er:YAG laser, having an energy density approximately equal to the ablation threshold of enamel. There was no significant difference observed in the final bond strength of most of the bonding systems used. Only one bonding system needed acid etching followed by laser irradiation. Reports of decreased bond strength values after additional laser conditioning may be due to the possibility of thermal damage or unfavorable surface modifications that may take place in the tissues due to increased energy deposition, and consequently depending on the chemistry of the bonding agent used, which would affect the bonding ability of enamel [11].

There are various clinical parameters and energy densities of Er:YAG laser-treated dentin surfaces that need to be optimized. Reduced values of bond strength were observed with changes in these parameters such as using much higher fluence than the ablation threshold of dentin and using it with a thick layer of bonding agent with no adhesive use.

Sealing of pits and fissures

The use of Er:YAG laser irradiation to perform minimally invasive occlusal preparations and to seal pits and fissures has been suggested. Er:YAG-lased enamel surfaces are devoid of smear layer, roughened, and present a micro-retentive structure similar to the etching pattern type I.

Erbium laser (Er,Cr:YSGG 2790 nm and Er:YAG 2940 nm)

Preparation speed

The water content of the tissue plays a major role in the ablation process and therefore carious tissue, sound dentin, and sound enamel present different ablation rates, which create the possibility of selective caries removal.

No ablation is observed when enamel is irradiated without water spray, but as expected, a higher ablation rate has been observed for dentin irradiated under these conditions [14]. Nevertheless, irradiation without water spray is absolutely contraindicated since it causes too much thermal damage to the tissue.

The tip material used in an Er:YAG laser also affects the energy output. The sapphire tips exhibit higher output energies as compared to the quartz tips. Contact ablation of enamel surface resulted in melted spots of tooth material on both types of tips with surface changes.

Besides the energy density applied, other factors can influence dental hard tissue ablation. The structure mode, which determines the energy distribution within the laser beam and the pulse duration also have been found to influence ablation [15, 16].

Very important for clinical procedures is the influence of the pulse duration. At shorter pulse durations, like 100 and 150 μs, enamel ablation begins already at 7 J/cm^2, which is 3 J/cm^2 lower than the ablation threshold. This means that shorter pulse durations, apart from leading to less thermal transfer to the surrounding tissue, also result in a more efficient ablation and should therefore be the choice for enamel and cavity preparation procedures [17].

Effective enamel, dentin, and bone cutting by means of an Er,Cr:YSGG laser was first demonstrated in the early 1990s [18]. By that time, the use of Er:YAG lasers in dentistry had already advanced, and most of the researchers concentrated on the 2.94 μm wavelength. Not until the beginning of this decade did the number of investigations concerning Er,Cr:YSGG laser applications in dentistry start to increase [19, 20].

The ablation efficiency is increased for both enamel and dentin when irradiation is performed in the presence of a water spray. With the same output power, irradiation with water results in statistically significant higher ablation depths

[21–23] Recently, studies have demonstrated that shorter Er,Cr:YSGG laser pulses promote more efficient enamel ablation, when used with water [24].

X-ray diffraction analysis of Er,Cr:YSGG laser-irradiated dentin surfaces showed that the inorganic hydroxyapatite structure in dentin remained almost unchanged, being 30 nm in size after laser treatment. An Er,Cr:YSGG laser was used at four different densities, of 6.18, 8.04, 9.89, and 11.1 J/cm^2. The thermal effects at these energy densities, used with a water-cooling spray system, however, induced some decrease in the organic matter in the superficial layer of dentin. The dentin surface was observed to be rough, clean, and with completely open dentinal tubules. The peri-tubular and inter-tubular dentin was ablated with the used energy densities, without any changes in gross appearance, making it favorable for the penetration of adhesive materials for adhesive restorations.

Recent investigations have showed a linear correlation between Er,Cr:YSGG laser ablation efficiency and the output power using linear regression analysis ($R^2 = 0.61$). The used laser was operating at a fixed pulse duration of 140 μs and a repetition rate of 20 Hz [25].

Laser caries removal versus high-speed drilling

The time required to prepare dental class V cavities with an Er,Cr:YSGG laser in sound human teeth is statistically higher than the time needed for mechanical bur preparation [26].

However, carious dentin removal from extracted human teeth has shown to be quicker with Er,Cr:YSGG laser irradiation at 4 W, 20 Hz (10 to 15 s) than with an air turbine [27]. Ablation is more efficient in carious dentin, as its water content is higher [28].

Dentin fluid perfusion through the dentinal tubules may influence the sensitivity of prepared and restored dentin. This mechanism of perfusion mainly depends on the surface composition and structure of the dentin. A comparison of bur-prepared and Er,Cr:YSGG laser-prepared dentin showed that Er,Cr:YSGG laser irradiation may render the surface dentin more sensitive and receptive to perfusion as compared to the bur-prepared dentin.

In a clinical trial of bur- and laser-prepared class I occlusal cavities, it was reported that the retention rates of laser-prepared cavities after 24 months were 100%. The marginal discoloration and marginal adaption rates for laser-prepared cavities were 7.4 and 13%, and for bur-prepared cavities were 5.6 and 9.3% respectively. Both methods of cavity preparation had comparable results in a clinical follow-up of 2 years.

The Er,Cr:YSGG laser cavity preparation did not differ from preparation with CVD, diamond, or carbide bur in terms of microleakage with the different adhesive systems. The aim of this study was to compare the effects of the Er,Cr:YSGG laser using chemical vapor deposition (CVD) and bur cavity preparation with conventional preparation methods, including a diamond bur and a carbide bur, on the microleakage with two different adhesive systems.

Temperature rise

Surface temperature measurements at the enamel ablation threshold show that a temperature increase around 800 °C can be observed [29]. A decrease in residual heat deposition during enamel ablation with the Er,Cr:YSGG laser can be obtained with shorter laser pulses. When pulse durations of 150 ns instead of 150 μs are employed, the residual heat deposition decreases from 59 to 39%. Water irrigation also results in a significant decrease of the residual heat deposition and does not compromise ablation efficiency.

Temperature measurements inside the pulp chamber during class V preparation with the Er,Cr:YSGG laser (6 W, 20 Hz, 68.2 J/cm^2) have showed the changes to be within a safe range. Even a decrease in pulp temperature up to 2 °C was observed [30] (Figs. 1, 2, and 3).

Pulp reactions

Investigations of Er,Cr:YSGG laser cavity preparation effects on rabbit and dog pulps showed adverse pulp reaction. In rabbits, the cavities were prepared for 6 s with either 2 W (22.6 J/cm^2), 3 W (33.9 J/cm^2), and 4 W (45.2 J/cm^2) at a repetition rate of 20 Hz. The preparation with 2 and 3 W both resulted in cavities penetrating 0.4 and 1 mm of the dentin respectively. Both failed to induce any inflammatory response to the pulp 12 h after the procedure. Similar responses were observed 1, 2, 7, and 30 days post-operation. At 4 W, laser cavity preparation resulted in pulpal exposure. The pulpal tissue exposed to Er,Cr:YSGG laser irradiation presented signs of soft-tissue coagulation, vasodilation, inflammatory cells infiltration, and intact ondotoblastic layer. Nevertheless, 48 h after exposure, inflammatory changes were no longer evident, and 7 days later, the tissue appeared normal [31] (Figs. 4, 5, 6, 7, 8, and 9).

Observations in dogs show that laser cavity preparation with 4 W (45.2 J/cm^2) and 5 W (56.6 J/cm^2) for 6 s at a repetition rate of 20 Hz did not show any inflammatory reactions. The pulps were vital and normal in appearance. Deeper preparations penetrating up to two thirds of the dentin thickness resulted in a slight increase of secondary dentin deposition, both by laser (5 W) and bur cavity preparation. Sixty days after the procedure, there was no evidence of periapical radiolucency [32].

Intentional pulp exposure by Er,Cr:YSGG laser irradiation (6 W, 67.9 J/cm^2) in the teeth of dogs resulted in pulpal inflammation 24 h after treatment. Observations after 7 days showed that the inflammation had progressed apically into the superior aspect of the radicular chamber.

Fig. 1 Cervical restorations with Er,Cr:YSGG

Fig. 3 Initial situation nos. 36–37

Histological studies regarding the effects of Er,Cr:YSGG laser cavity preparation in human tooth pulps could not be found. Although the studies in dog and rabbit teeth showed no damage to pulpal tissue, it would be interesting to investigate whether the same results are to be observed in studies on human subjects. Rabbit teeth, for instance, have a higher healing potential due to their wider apical foramen and substantial vascularization of the pulp. Animal models provide interesting observations of biological response to treatment, but final evidence has to be obtained from human subjects.

The measurements of temperature changes in the pulp of dog teeth recently sacrificed showed that during Er,Cr:YSGG laser cavity preparation (6 W, 20 Hz, 68.2 J/cm^2), the pulp temperature sunk to about − 0.5 °C on average. The same measurements in extracted human molars resulted in a mean pulp temperature drop of − 1.9 °C. The temperature changes registered in this study are within the safe range for maintaining pulp vitality (see [30]).

In summary, Er,Cr:YSGG laser cavity preparation caused no irreversible inflammatory response in animal models as long as the pulp chamber was not exposed. Pulpal temperature rise measurements in vitro also showed a safe temperature increase for the pulp. However, further human clinical trials have to be conducted in order to clarify human pulp vitality after cavity preparation with the 2.79 μm wavelength [33].

Minimally invasive caries removal

As carious dentin and enamel possess a much higher amount of water than sound dental tissues, the intrinsic tissue properties allow for a selective ablation. In this case, the delivered laser energy has to be lower than the ablation threshold for sound enamel and dentin ablation, but high enough to cut the diseased tissues [34].

The combination of laser fluorescence by means of a diode laser in Er:YAG laser equipment has shown to provide secure information and to be able to guide selective ablation [35]. Furthermore, acoustic feedback mechanisms have also been developed to guide selective ablation.

A comparative study between root caries removal techniques using bur and Er,Cr:YSGG laser was conducted to assess the marginal seal of composite resin restorations and cavity characteristics after caries removal. An Er,Cr:YSGG laser was used ($\lambda = 2.78$ μm, 20 Hz, pulse duration approximately 140 μs, noncontact mode using a 600-μm tip) with

Fig. 2 Cervical restorations with Er,Cr:YSGG

Fig. 4 Initial situation nos. 36–37

Fig. 5 Er,Cr:YSGG no. 36–37 caries removal with a MZ6 tip

power outputs ranging from 1 up to 4 W. It was observed that laser caries removal showed an increased amount of microleakage indexes, cavity depths, and the presence of residual caries as compared to the conventional method. Therefore, it was concluded that Er,Cr:YSGG laser irradiation is not a preferred method for root caries removal over the conventional method due to excessive loss of marginal seal in composite resin restorations.

A similar study was conducted earlier to assess the microleakage of conventional glass ionomer restorations for root caries. Various methods were employed in the study, including hand-held excavators, spherical carbide burs on slow speed handpiece, and Er,Cr:YSGG laser used at power outputs of 2.25, 2.5, and 2.75 W, with 55% air and 65% water during the irradiation process. The Er,Cr:YSGG laser at 2.5 W and energy density of 44.64 J/cm^2 showed the minimum amount of microleakage.

The selectivity of Er,Cr:YSGG lasers in ablating dental tissues should be better investigated in the future because the evolution of these systems may pave the way for very modern and conservative dentistry. The future implementation of scanners and feedback systems in laser handpieces used for caries removal have the potential to increase the precision and

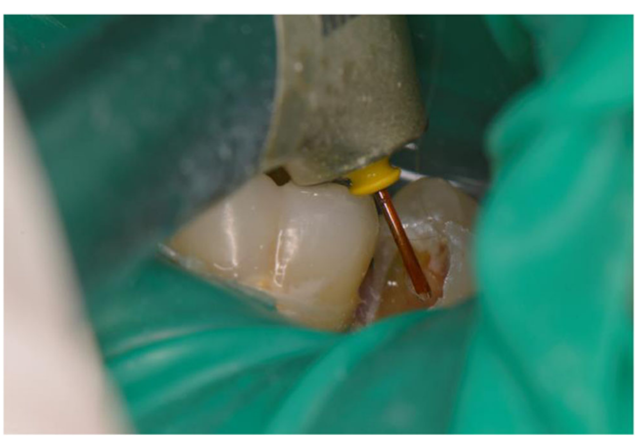

Fig. 6 Er,Cr:YSGG no. 36–37 caries removal with a MZ6 tip

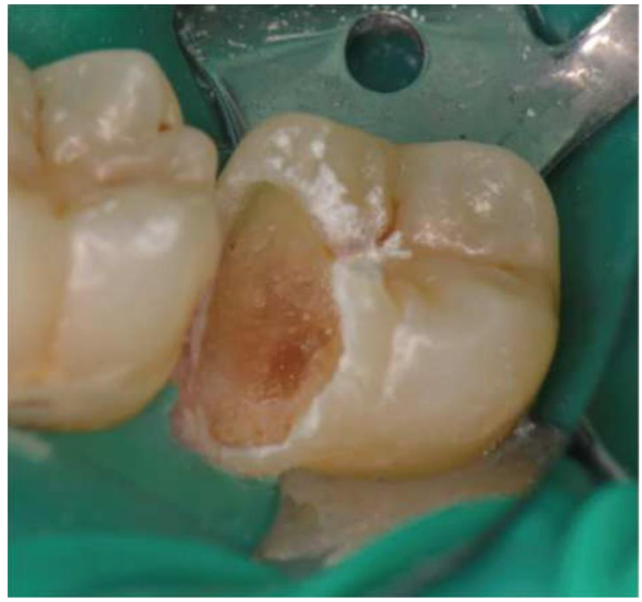

Fig. 7 Cavity after caries removal

standardization of caries treatment. Nevertheless, studies have just started to investigate these possibilities. So far, laser permits a selective ablation mainly based on the tissue absorption coefficients.

Bactericidal effect

Bacterial elimination has been stated to be one of the great advantages of laser caries removal. This bacterial killing effect has been demonstrated for different wavelengths and different irradiation conditions. Recently, as the use of the 2.79 μm

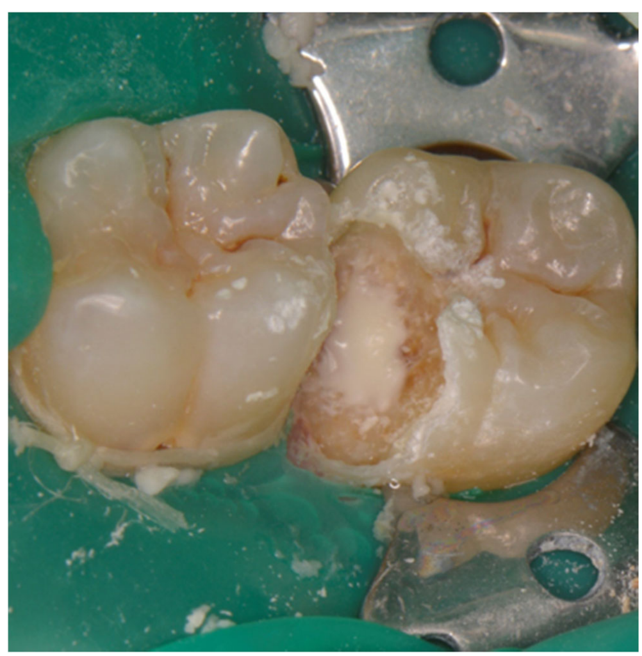

Fig. 8 GIC placement

Fig. 9 Er,Cr:YSGG no. 37, final view after 4 months

wavelength in dentistry increased, the Er,Cr:YSGG laser has been investigated for its antibacterial effect.

The irradiation of root dentin slices of 1 mm with 1.5 W and 20 Hz at an incidence angle of 10° in 5 cycles of 5 s each (15 s intervals) resulted in bacterial reduction from both *Escherichia coli* and *Enterococcus faecalis*. However, total eradication of *Escherichia coli* and *Enterococcus faecalis* was observed in only 7 of 20 and 1 of 20 samples respectively [36].

In the same study, the irradiation with an Er:YAG laser with 1.5 W, 15 Hz, and the same application, conditions resulted in complete *Escherichia coli* eradication in all of the 20 samples and in *Enterococcus faecalis*, eradication in 8 of 20 samples.

The ability of Er,Cr:YSGG laser irradiation to kill *Streptococcus mutans* has also been investigated. This microorganism is directly related to caries occurrence and, therefore, is of the highest interest for investigations regarding bacterial effects after laser cavity preparation. Cavity preparation with the Er,Cr:YSGG laser at 0.75 and 1 W output power and 20 Hz repetition rate resulted in a statistically similar disinfectant potential in cavity walls to the use of chlorhexidine gluconat-based disinfectant solution. When compared to control non-treated cavities, Er,Cr:YSGG laser irradiation resulted in a statistically significant lower bacterial recovery [37].

The evidence from the currently available in vitro studies shows that the Er,Cr:YSGG laser has an antibacterial effect on different microorganisms, including *Streptococcus mutans* (Figs. 10, 11, 12, 13, 14, 15, 16, and 17).

Pain perception and patient acceptance

The evidence of effective enamel and dentin ablation with Er,Cr:YSGG laser irradiation was obtained 6 years after the Er:YAG laser [38]. That is why there is less clinical evidence investigating patient acceptance and pain perception of Er,Cr:YSGG laser cavity preparation.

In a split-mouth, double-blind, randomized study, Hardley et al. compared the clinical outcomes of caries removal and cavity preparation in 68 patients. Enamel preparation was carried out at a power setting of 5.5 to 6 W and dentin at 4 to 5 W, both with a repetition rate of 20 Hz. The intra-operative evaluation showed that 98.5% of the subjects felt no discomfort during and after laser cavity preparation, while the discomfort felt with air turbine/bur preparation was significantly higher. All Er,Cr:YSGG laser-irradiated teeth remained vital during a 6-month follow-up evaluation [39].

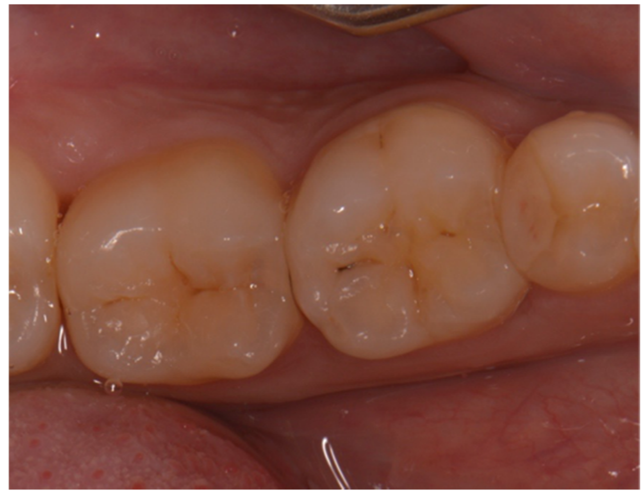

Fig. 10 Er,Cr:YSGG Case No. 46–47 deep caries

Matsumoto et al. [40] conducted a study in which 50 cavities were prepared with the Er,Cr:YSGG laser in 44 previously informed patients. Caries removal and cavity preparation were done using 3–6 W output power and a repetition rate of 20 Hz. Sixty-eight percent of the patients felt no pain at all during the treatment, and it was considered comfortable by 84% of the subjects. In 94% of the cases, treatment was performed without anesthesia. The time needed to prepare classes III, IV, V cavities lays between 1 and 5 min and classes I and class II, between 10 and 20 min.

In a clinical trial conducted among children between 7 and 12 years of age, cavity preparation was performed using Er,Cr:YSGG laser and conventional mechanical preparation.

Fig. 11 No. 46–47 deep caries

Fig. 12 No. 47 exposed pulp

The evidence observed in the currently available clinical trials shows that caries removal and cavity preparation with an Er,Cr:YSGG laser is indeed more comfortable than conventional treatment with high-speed burs. A high percentage of the patients also sensed no pain at all during laser treatment of different cavity preparation types.

Surface roughness, conditioning, microleakage

In general, the enamel surfaces irradiated with the Er,Cr:YSGG laser under water cooling present no evidence of carbonization or melting (Fig. 14). The surfaces present a smooth appearance and roughened patterns. Dentin surfaces also do not show signs of melting or carbonization, presenting open dentinal tubules, more prominent peritubular than intertubular dentin, and absence of smear layer. The openings of the peritubular dentin were more prominent than those of the intertubular dentin (Fig. 14). The morphology patterns of laser-irradiated enamel and dentin present an interesting

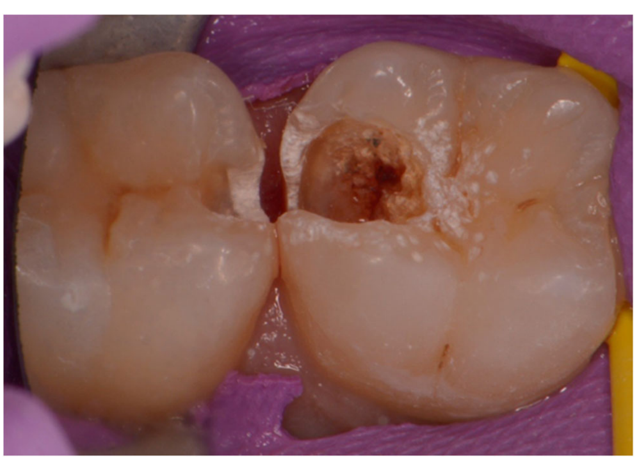

Fig. 13 Er,Cr:YSGG laser pulp capping

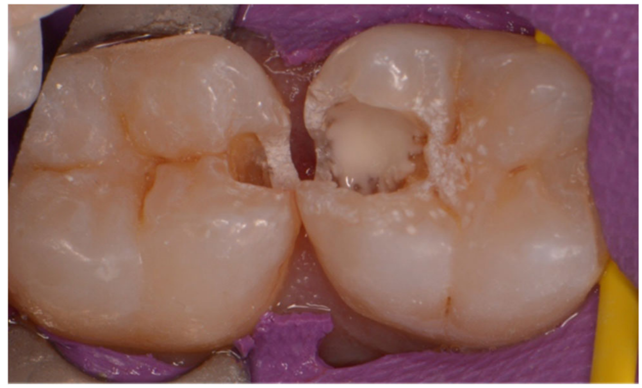

Fig. 14 Calcium Hydroxide and GIC placement

aspect for adhesive bonding procedures, which require clean surfaces with mircroretentive characteristics [41–43].

The review of the literature regarding bond strength after conditioning dental surfaces with the Er,Cr:YSGG laser shows that results are still controversial, and that possibly the different results are due to the many differences in irradiation conditions. Precise beam measurements, knowledge about the beam profile, number of pulses applied, pulse overlapping, and pulse duration provide important information about the laser/tissue interaction and can have a direct influence on the bonding to lased dental surfaces. Much of the literature regarding the use of lasers in adhesive dentistry lack these important pieces of information, which in turn makes it difficult to extract standardized, reproducible evidence from them.

Although the studies presented here are poorly reproducible, they show what might be achieved with Er,Cr:YSGG laser irradiation prior to bonding procedures. In enamel, most of the studies show that Er,Cr:YSGG laser conditioning leads to bond strength means similar to acid-etched surfaces. Irradiation at 2 W, 20 Hz with a fluence of 5.6 J/cm^2, and a pulse duration of 140 μs under water spray leads to high bond strength means in different studies with different ways of energy delivery [44, 45]. Nevertheless, the same parameters lead to lower bond strength means than the acid-etched surface. Bond strength similar to control acid-etched surfaces could only be obtained with a higher output power of 3 W [46].

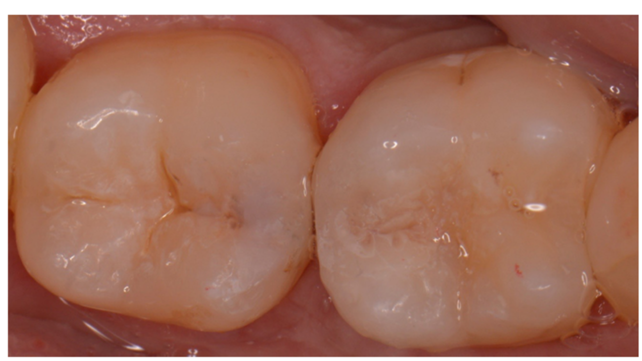

Fig. 15 Er,Cr:YSGG final restorations on 46/47 after polishing

Fig. 16 Er,Cr:YSGG Case final restorations on no. 46–no. 47

This difference in results for the same laser parameters illustrates the influence of the manner in which energy is delivered into the tissue. In summary, although the exact laser parameters and energy delivery settings cannot be determined, bond strength similar to acid-etched surfaces can be obtained through Er,Cr:YSGG laser enamel conditioning [47]. The same applies for bond strength to Er,Cr:YSGG laser-irradiated dentin [48].

Enamel surface conditioning for professional fluoride application has also been studied with the Er,Cr,YSGG laser. It was reported that at 8.5 J/cm^2, Er,Cr:YSGG laser followed by acidulated fluoride phosphate treatment was able to reduce enamel demineralization, which was not seen in the APF application alone, and increased the retention and formation of CaF2 on enamel. The Er,Cr:YSGG laser, combined with acidulated fluoride phosphate, reduces enamel demineralization when compared to APF treatment or laser treatment alone.

There are different irradiation settings in the literature about Er,Cr:YSGG laser treatment of enamel or dentin surface, suggesting the 5 W power setting for dental restoration applications in terms of shear bond strength and activation area, with other publications suggesting re-etching with acid phosphoric if an Er,Cr:YSGG laser (1.5 W for enamel, 1 W for dentin etching) is used for tooth preparation or surface treatment during 40 s [49–51].

Fig. 17 Recall after 4 months–vital no. 46+

The surface of dentin has been modified using various techniques to increase the mechanical retention with adhesive materials. One of these techniques is the placement of a stainless steel mesh work mask over the dentin surface during Er,Cr:YSGG laser irradiation. This creates a textured surface having uniform craters of 100 μm wide and 150 μm deep, resulting in better mechanical retention [52].

The bonding effectiveness of adhesives to laser-irradiated enamel depends not only on the structural substrate alterations induced by the laser, but also on the characteristics of the adhesive employed [53]. To obtain the maximum retention of a glass ionomer restoration to Er,Cr:YSGG laser-irradiated dentin, pre-treatment of the laser-prepared dentin with dentin conditioner is advantageous [54].

In the sandwich technique, the adhesion between materials is of importance for the overall restoration. The shear bond strength between GIC and composite resins is affected by the type of cement used, the method of surface treatment, and the interaction of these two factors. In RMGIC, Er,Cr:YSGG laser irradiation for 15 s with 1 W (17.7 J/cm^2), 600 μm tip placed perpendicular to the surface at 1 mm distance, showed higher bond strength than the phosphoric acid treatment. The bond strength values were similar in conventional GIC surface treatment with both conditioning methods [55].

Etching with an Er,Cr:YSGG laser at 1.5, 2.25, 3, and 3.5 W has no change on the mineral content of dentin when compared to the conventional acid etching or air abrasion methods. The Ca, P, Na, and the Ca/P ratio remained significantly unaltered [56].

Bond strength of one-step self-etch resin showed the highest bond strength to laser-irradiated enamel, compared to the other adhesive systems [57–59]. When the tensile bond strength of a self-etching primer system to enamel and dentin surfaces treated with Er:YAG (350 mJ, 10 Hz, 20 J/cm^2 for enamel; 300 mJ, 6 Hz, 17 J/cm^2 for dentin) and Er,Cr:YSGG laser (125 mJ, 20 Hz, 16 J/cm^2 for both substrates) were evaluated, the self-etching system adhesion was influenced by the type of erbium laser used, and the bond strength was higher in the Er,Cr:YSGG laser-irradiated surfaces than in the Er:YAG laser-irradiated ones [60].

Re-etching with phosphoric acid is recommended for enamel and dentin surfaces treated with Er,Cr:YSGG laser to increase the micro-shear bond strength of composite restorations.

Various cavity disinfectants, chlorhexidine, sodium hypochlorite, propolis, ozone, and Er,Cr:YSGG laser were tested to reveal that the bond strength of silorane-based resin composite was not affected by the use of any disinfectant [61].

A similar group performed a comparative study to evaluate the effects of Er,Cr:YSGG laser and other cavity disinfecting agents (2% chlorhexidine gluconate, propolis, and ozone) used with etch-and-rinse and self-etch adhesives in a class V cavity preparation. The etch and rinse adhesives showed no difference in any disinfectant treatment, but self-etch adhesives showed differences in the groups of the Er,Cr:YSGG laser and chlohexidine treatment on enamel. Microleakage measurements were similar in all disinfectant treatments used with etch and rinse adhesives. Self-etch adhesives showed differences in microleakage depending on the disinfecting agent used [62].

The Er,Cr:YSGG laser at 20 Hz, 0.75 W, 15% water, and air, when used as a disinfecting agent, did not affect the bonding of etch and rinse or self-etch cements adversely [63].

The strength of the bond between the composite resin and the dentin is also affected by hybridization and resin tag formation. Lee et al. [64] demonstrated that the resin tag formation seen in laser-treated dentin was similar to that seen in acid-etched dentin.

Regarding a marginal seal of the restorations after laser cavity preparation and laser conditioning with Er,Cr:YSGG laser, the evidence is controversial and therefore indicates that additional acid etching after laser irradiation is needed [65–67].

The Er,Cr:YSGG has been used at different output powers to evaluate the possibility of finding an alternative to acid etching for the bonding of dual-cure resin luting agents. It was reported that laser irradiation at 1.5W, 1.75W, and 2 W for 15 s created a surface with type III acid-etched pattern, similar to the one with acid etching [68].

The repair shear bond strength of silorane-based composites was reported to be acceptable when treated with an Er,Cr:YSGG laser [69].

Ceramic/dentin bond joint is a critical determinant in prosthodontic dentistry. A comparative study was performed between the shear bond strength of ceramics and dentin prepared by diamond bur or Er,Cr:YSGG laser at 2 W, 30 Hz, 50% water, and 70% air. It showed that Er,Cr,YSGG laser irradiation may produce a stronger bond between the ceramic and the dentin surface, but this depends on the additional factor of choice of adhesive system [70].

Sealing of pits and fissures

The use of Erbium laser for sealing pits and fissures prior to sealant application has been suggested because of its ability to generate rough enamel surfaces free of a smear layer. The irradiation of enamel fissures with the Er,Cr:YSGG laser has shown to result in low microleakage degrees, comparable to non-treated surfaces, when the irradiation is followed by acid etching and direct sealing. When the bond strength of Er,Cr:YSGG laser-irradiated enamel to dentin is assessed, the same necessity for subsequent acid etching is noted [64].

One of the greatest advantages claimed for the use of Er,Cr:YSGG laser irradiation in the preparation of pits and fissures for sealing was the possibility of achieving more caries-resistant enamel surfaces through a very conservative preparation [71]. This is still a controversial topic in the literature though, and some studies did not find the same increase in enamel caries resistance after Er,Cr:YSGG laser irradiation [72, 73].

In summary, pits and fissures can be prepared with Er,Cr:YSGG laser irradiation and result in good marginal sealing, as long as acid etching is performed after the irradiation. A tendency for the Er,Cr:YSGG laser to increase enamel caries resistance has also been observed, but the findings in the literature are still controversial and, therefore, this should not be the main objective of the treatment.

The need for acid etching was not disregarded and was considered important for enamel surface treatment prior to the placement of fissure sealant after using Er:YAG laser irradiation, metal bur, and CoJet pre device. Laser etching at 2 W (20 Hz or 40 Hz) may be an alternative to conventional acid etching [74].

Use of an Er,Cr:YSGG laser showed no significant difference in bond strength values between enamel surfaces treated with laser or with acid etch alone. It did not enhance the effect of acid etch in increasing the bond strength of the fissure sealant to the enamel surface [75].

A 24-month clinical trial was conducted to compare the clinical performance of sealants placed over acid-etched or laser-treated surfaces. It was observed that 83.9% of the sealants placed on Er,Cr:YSGG laser-etched surfaces were "completely retained... no significant differences were observed between the retention rate of both methods of preparation." The clinical performance of fissure sealants placed after acid or Er,Cr:YSGG laser etching was similar [76].

Removal of old fillings

The removal of dental restorative materials, such as composites and cements, is also possible with the Er:YAG laser [77]. The infrared transmission spectra of composite resins indicate strong absorption at 3 μm. The main components of composite resins are quartz and water. These absorption characteristics of composite contents indicate that the ablation process for the removal of old fillings observed in the Er:YAG wavelength of 2.94 μm also applies for the Er,Cr:YSGG laser [78]. Therefore, gold, amalgam, and ceramic restorations cannot be removed.

Conclusions

Erbium family lasers are a valuable state-of-the-art tool for every clinician. The two Erbium family wavelength characteristics have proven to be efficient in carious lesion removal, with a number of advantages over the classical bur, including bactericidal effects and pulp protection. Dentists and patients are both benefited by implementing Erbium family lasers in composite restorations. Nevertheless many aspects of the operative dentistry field have yet to be addressed by future studies including optimal settings and special adhesives for laser-prepared cavities in order to have a clearly increased bonding strength against classical procedures.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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