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Chemical Treatments of Dental Surfaces Prepared with Er:Yag and Er,Cr:YSGG Lasers: A Literature Review

Hafsa El Merini[1], Sofia Drouri[1], Jawad Essafi[2], Mouna Jabri[1], Amal El Ouazzani[1]

[1]Department of Conservative Dentistry and Endodontics, Faculty of Dentistry, University Hassan II of Casablanca, Casablanca, Morocco
[2]Private Practice, Casablanca, Morocco
Email: sofia.drouri@gmail.com

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Abstract

The indications of lasers in dentistry are numerous. The aim of this review is to compare the adhesion to cavities prepared with Er:YAG and Er,Cr:YSGG lasers with conventional techniques (rotary bur) and consequently highlight the most appropriate adhesion protocol(s) to cavities prepared by either technique. A literature search was conducted in three databases: PubMed, Google Scholar, and ScienceDirect. For outcomes, the morphological changes of the dental surfaces following laser irradiation are multiple: absence of dentinal sludge, open dentinal tubules, abundant peri-tubular dentin and exposed enamel crystals. Bonding to this dental substrate can be achieved using various adhesive systems. The chemical treatment of laser-prepared dental surfaces is a subject that still requires more precise and further studies are needed to establish universal protocols and recommendations of good practice.

Subject Areas

Dentistry

Keywords

Lasers, Adhesive Systems, Dentin, Enamel, Bonding, Er:YAG, Er,Cr:YSGG, Cavity Preparation

1. Introduction

Cavity preparation has long been done with diamond or tungsten carbide burs mounted on high and low-speed rotary instruments. This model has partially changed since the introduction of new technologies, including the use of lasers, which allow less invasive treatments for caries removal [1] [2].

High-power lasers have been introduced in dentistry as an alternative for cavity preparation and to promote chemical and morphological changes on the tooth surface [3]. The advantages of using lasers for dental hard tissue preparation include selective removal of decayed enamel and dentin, bactericidal effects, with less noise and vibration and discomfort to the patient.

Erbium (Erbium:Yttrio-Aluminum-Granate) lasers (Er:YAG and Er,Cr:YSGG) are considered the most effective lasers for mineralized tissues because their wavelengths have high absorption by water and hydroxyapatite [3]. The Er:YAG laser wavelength (2940 nm) has the highest water absorption of all currently used wavelengths and also has a high affinity for hydroxyapatite [2]. Indeed, ablation is achieved by a thermomechanical interaction. When the laser is used with air and water as a cooling system, it has been shown that it does not produce undesirable changes in enamel, dentin and pulp [4] [5]. With the Er,Cr:YSGG laser (2780 nm), dentin removal is thermomechanical. The emitted laser light is absorbed by the water contained in the hydroxyapatite of the dental hard tissue [6] [7]. The water is then heated and evaporated, producing a high vapor pressure that causes a micro-explosion of the dental tissue below the melting point of the dental tissue (approximately 1200˚C) [8].

The aim of this review is to determine the effect of laser irradiation on dental tissues through the evaluation of various changes in the chemical and morphological configuration of the irradiated substrate and to study the performance of adhesive systems on laser-prepared dental surfaces.

2. Material and Methods

2.1. Search Strategy

The MeSH descriptors/terms used in the databases are:

PubMed: Dental and adhesive systems and lasers;

Google Scholar: Er:YAG and Er:Cr/YSGG and cavity preparation and adhesive systems;

ScienceDirect: Dentin and enamel AND Er:YAG and Er,Cr:YSGG and adhesive systems and Bonding.

2.2. Inclusion Criteria

- Studies conducted in the last five years;
- Studies comparing chemical treatments of dental surfaces prepared with Er:YAG and Er,Cr:YSGG lasers to dental surfaces prepared with conventional methods (burs + rotary instrument);
- Comparative studies between self-etching systems "SAM" and etching and rinsing systems "M&R" and universal systems;
- Articles concerning only permanent human teeth;
- Articles in English.

2.3. Exclusion Criteria

- Articles that do not fit the research question by reading the abstracts and the full text.

3. Result

The search performed on the three databases (PubMed, Google Scholar, Science-Direct) using Boolean equations identified a total of 773 articles.

After deleting duplicates, a first selection based on the reading of the titles resulted in 132 articles.

Among the 132 articles, 24 were eliminated after reading the abstracts, and 108 articles were retained for full text reading.

In the end, 13 articles were retained in the present study in Figure 1.

The articles included in this study are presented in Table 1.

4. Discussion

The purpose of this work was to conduct a detailed literature review of the studies collected concerning chemical treatments of dental surfaces prepared with Er:YAG and Er,Cr:YSGG lasers.

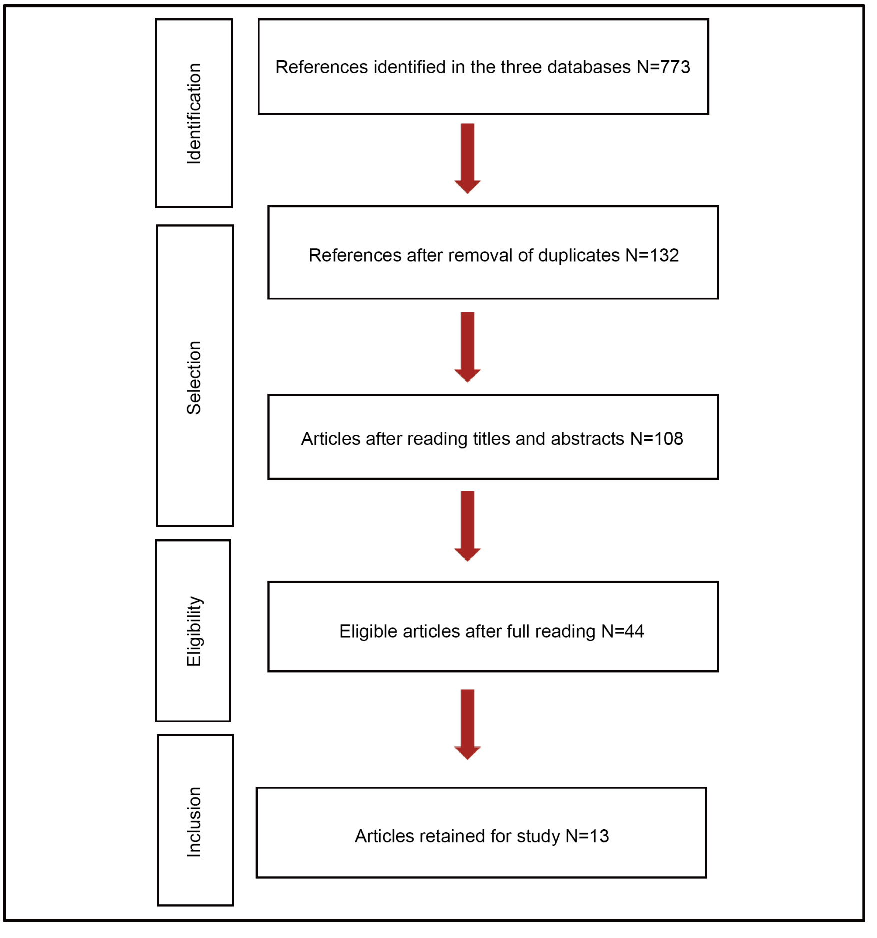

Figure 1. Flow chart.

Table 1. Data extraction table for selected articles.

Author/Year/ Type of study	Sample size	Objective of the study	Laser parameters	Comparison	Results
Tzimas K. [9] *et al.* 2019 *In vitro*	45 teeth of wisdom	Comparison of cavities prepared by diamond bur with Er,Cr:YSGG	Er,Cr:YSGG P = 6 W/F = 30 Hz Pulse duration: 140 µs Cooling: 60% air and 90% water Energy density: 70.77 J/cm² For surface treatment: P = 4.5 W/F = 50 Hz Pulse duration: 140 µs Cooling: 60% air, 90% water Energy density: 31.85 J/cm²	**G1:** diamond bur + 37% phosphoric acid for 30s. **G2:** diamond bur+ Er,Cr:YSGG laser for surface treatment. **G3:** Er,Cr:YSGG laser for cavity preparation without surface treatment. **G4**: preparation of the cavity by the Er,Cr:YSGG laser + phosphoric acid 37% for 30s for surface treatment. **G5:** Er,Cr:YSGG laser for cavity preparation and surface treatment.	-The use of the Er,Cr:YSGG laser is a valid alternative approach for cavity preparation.
Dönmez N. [10] *et al.* 2019 *In vitro*	24 decayed molars	To study the micro-tensile strength (micro-TBSs) of four universal adhesive systems, applied in two different bonding techniques (etch/rinse and self-etch), to affected dentin irradiated with Er:YAG laser	Er:YAG Parameters used: P = 3.5 W Pulse duration = 300 µs F = 10 Hz Energy density: 44 J/cm² Cooling: air and water spray	-MR: Clearfil Universal Bond > All Bond Universal -SAM: Single Bond Universal (10 MDP monomer) > Prime & Bond One Select (without 10 MDP monomer). -Prime & Bond One Select (without 10 MDP monomer) and Single Bond Universal (with 10 MDP monomer) similar in M&R or SAM mode.	-The caries removal technique and the universal adhesives used in M&R or SAM mode affect the bonding properties to the affected dentin. -Irradiation with Erbium lasers causes a change in the chemical configuration of the tooth structure, producing acid-resistant surfaces. -SAM or M&R universal adhesives can be used for adhesive restoration of decayed dentin after Er:YAG laser irradiation. -Adhesives play an essential role in the bond strength of MDP-containing materials.
Bishnoi AK. [11] *et al.* 2019 *In vitro*	80 premolars	Evaluate the effect of Er:YAG cavity preparation on the bonding quality of SAM systems with and without HEMA	Er: YAG E: 490 mJ F = A5Hz	**G1:** 40 teeth (carbide bur-prepared cavity) • Subgroup A1 (G-Bond) • Subgroup A2 (Adper Easy One) **G2:** 40 teeth (Er:YAG-prepared cavity) • Subgroup A2 (G-Bond) • Subgroup B2 (Adper Easy One) Then obturation with One-step self-etch—HEMA-free or HEMA-rich.	-The effect of the Er:YAG laser for cavity preparation did not show any performance in terms of adhesion when using the seventh-generation adhesives (Adper Easy One and G-Bond bonding agents)

Continued

Cebe F. [12] *et al.* 2017	10 decayed molars	To evaluate the effect of the Er:YAG laser on the bond strength of an M&R adhesive system to carious dentin on the cervical wall.	Er:YAG Parameters used: P = 3.5 W Pulse duration: 300 µs F = 10 Hz Energy density: 44 J/cm^2 Cooling: air and water spray	**G1:** Bur-prepared cavity **G 2:** Laser Er:YAG-prepared cavity The teeth were then restored with an M&R adhesive system (Adper Single Bond 2) and a composite resin (Filtek Z250).	-No statistically significant difference was found between the Er:YAG laser and the bur-treated group with respect to the bonding properties. -The Er:YAG laser treatment had no negative effect on the bonding performance of the total-etch adhesive system on the carious dentin of the cervical wall.
Chen ML. [13] *et al.* 2015	160 teeth	To evaluate the effect of pretreatments on the performance of all-in-one self-etching adhesives on Er:YAG laser prepared dentin.	Er:YAG Parameters used: P = 4 W Pulse duration = 100 µs E = 200 mJ F = 20 Hz Energy density: 25.46 J/cm^2	**8 groups:** N = 20 for each group: −37% phosphoric acid for 15 s Or low fluence irradiation with Er:YAG laser and then laser on 4 mm diameter with Smart-2940 D Er:YAG laser. -G-Bond Plus (G) or Xeno V (X) self-etching adhesive was used for dentin bonding. -2 control groups: G BOND PLUS or XENO V without laser treatment	Er:YAG laser preparation does not compromise the effectiveness of one-step self-etch adhesives and phosphoric acid pretreatment. Low-fluence Er:YAG [150 mJ; 10 Hz; short-pulse mode (SP, 300 µs); average power of 1.5 W; 19.10 J/cm2 energy delivered/pulse;10 ml/min water spray] can significantly increase tensile strength.
Ramos TM [3] *et al.*	96 third molars extracted	To evaluate the effect of different surface treatments on the morphology of dentin showing erosion "acid etch erosion cycle: immersion in citric acid solution (0.05 M, PH = 2.3), for 10 min and six times a day for five days" and on the tensile strength (µTBS) of the adhesive systems (Clearfil SE Bond "SAM" and Single Bond "M&R") to the dentin substrate.	Er:YAG: 60 mJ, 2 Hz, 0.12 W, 19.3 J/cm^2 Er,Cr:YSGG: 50 mJ, 1.5 W, 30 Hz, 4.5 J/cm^2, spray 70% eau et 65% air	**G1:** Polishing control / discs + SAM "Clearfil SE Bond" adhesive. **G2:** Diamond bur + SAM adhesive "Clearfil SE Bond" **G3:** Er:YAG laser (60 mJ, 2 Hz, 0.12 W, 19. 3 J/cm^2) + SAM adhesive "Clearfil SE Bond" **G4:** Er,Cr:YSGG laser + "Clearfil SE Bond" SAM adhesive **G5:** Polishing control/discs + M&R "Single Bond" adhesive **G6:** Diamond bur + M&R "Single Bond" adhesive **G7:** Er:YAG + M&R "Single Bond" adhesive **G8:** Er,Cr:YSGG + M&R "Single Bond" adhesive	Group G4 (Er,Cr:YSGG laser + SAM adhesive) showed the highest adhesion value. Er,Cr:YSGG significantly increases the adhesion to eroded dentin.
Vohra F [14] *et al.* 2018	80 third human molars	To evaluate the surface treatment of dentin by phototherapy (Er,Cr-YSGG laser) in the presence of different adhesive systems and their shear strength as well as the percolation phenomena.	Er,Cr:YSGG	**Group 1:** 40 teeth treated with diamond bur -20 treated with MR -20 treated with SAM **Group 2:** 40 teeth with Er,Cr YSGG laser: 50 Hz; 4.5 W; 60 s of application. -20 treated by MR -20 treated by SAM	Adhesion strength Lowest: laser + SAM Highest: diamond bur + M&R Laser Er,Cr:YSGG + M&R = favorable adhesion strength (comparable to that obtained by conventional methods: diamond bur + M&R adhesive)

Continued

Takada M [15] *et al.* 2015	70 teeth extracted	To evaluate the bond strengths obtained by using different adhesive systems on Er,Cr:YSGG laser prepared dentin	Er,Cr:YSGG Parameters used: **For email:** 3 W, 20 Hz, pulse duration 140 µs, 75% water spray and 85% air spray, 76.43 J/cm^2 **For dentin:** 2 W, 20 Hz, pulse duration 140 µs, 75% water spray and 60% air spray, 50.96 J/cm^2.	Each laser prepare enamel or dentin surface was treated with: Control group: two-step self-etch bond primer (SBP) and one-step self-etch bond/bond (SBB) + 10s photopolymerization, without prior laser treatment. **G1:** SAM "SBB" + 10 s light cure **G2:** SAM "SBP" 20 s + drying + "SBB" adhesive + 10 s light curing. **G3:** phosphoric acid 40% + SAM "SBP" 20 s + adhesive "SBB" + photopolymerization 10 s **G4:** 40% phosphoric acid + 10% sodium hypochlorite for 90 s + Rinse and dry + "SBP" adhesive 20 s + "SBB" adhesive + 10 s light curing **G5:** All-in-one adhesive (TSB) 20 s + Air jet + Photo-curing 10 s **G6:** 40% phosphoric acid + 10% sodium hypochlorite for 90 s + Rinsing and drying + All-in-one adhesive (TSB) 20 s + Photo-curing 10 s	-Adherence strength: Control group > than other groups Laser and SAM = rotary bur prepared enamel Phosphoric acid or phosphoric acid followed by sodium hypochlorite increased the bond strength of the composite resin to enamel and dentin prepared with an Er,Cr:YSGG laser.
Ahmed ZA [16] *et al.* 2015	21 healthy third molars were used	To evaluate the effect of three different adhesive systems on the shear strength of Er,Cr:YSGG laser prepared dentin composite resin.	Er,Cr:YSGG 3 W, 20 Hz, pulse duration 140 µs, 65% water spray and 70% air spray	**G1:** full-etch adhesive **G2:** two-step self-etch adhesive **G3:** all-in-one adhesive Two layers of composite were applied to the dentin surfaces and light cured for 40 s. The specimens were placed in a special device mounted on a universal testing machine (digital dynamometer, IMADA CO., LTD, Japan), to evaluate the shear strength.	-All tested adhesive systems have relatively the same effect on the shear strength of the composite resin on the surface of Er,Cr:YSGG laser-irradiated dentin
Kallis A [17] *et al.* 2018	63 healthy human molars randomized into four groups (n = 15).	Evaluate the thickness and qualitative characteristics of the hybrid layer after two methods of cavity preparation, using an Er:YAG laser in QSP mode and conventional tungsten carbide burs. To study the behavior of two different adhesion techniques using etch-and-rinse and self-etch adhesive systems.	Er:YAG 2940 nm, 3.75 W, 15 Hz, 250 mJ, water spray 20 ml/min, in QSP mode	2 groups prepared by Er:YAG laser 2 groups of tungsten carbide burs Adhesion with GLUMA® 2 Bond (etching and rinsing) and ClearfilTM Universal Bond Quick (self-etching). The thickness of the hybrid layer was measured with a scanning electron microscope (SEM).	-Higher hybrid layer in the group treated with laser and with the etching and rinsing technique.

Continued

Guven Y [18] *et al.* 2015	120 healthy human molars	Evaluate the shear strength (SBS) of a micro-hybrid composite resin bonded with three different adhesive systems to Er:YAG laser (EL) or burs prepared dentin surfaces. Analyze the quality and ultrastructure of the adhesive-dentin interfaces by scanning electron microscopy (SEM).	Er:YAG 200 mJ/20 Hz for enamel preparation and 80 mJ/10 Hz for dentin etching	**G1:** Er:YAG + Clearfil Tri-S Bond (S3) (universal adhesive) **G2:** Er:YAG + Adper SE Plus (SE) (two-step SAM) **G3:** Er:YAG + laser etching + Adper Single Bond 2 (all-in-one SAM adhesive) **G4:** Er:YAG laser + acid etching + Adper Single Bond 2 (all-in-one SAM adhesive) **G5:** Er:YAG laser + no etching + Adper Single Bond 2 (all-in-one SAM adhesive) **G6:** diamond bur + acid etch + Adper Single Bond 2 (all-in-one SAM adhesive) **G7:**diamond bur + Clearfil Tri-S (C3S) Bond (universal adhesive) **G8:** diamond bur + Adper SE Plus (SE) Bond (two-step SAM)	-Adhesion to dentin: Er:YAG laser ≫ rotary bur preparation
Shadman N [19] *et al.* 2019	30 healthy human molars,	To compare the shear strength (SBS) of a universal adhesive (scotchbond) with different modes of etching to Er,Cr:YSGG laser prepared dentin and bur.	Er,Cr:YSGG	3 groups: Prepared by bur and Er,Cr:YSGG laser (4 Watt and 5-Watt, 20 Hz, 96% water, 60% air, and 600-µm tip size). Each group was randomly divided into 2 subgroups (M&R and SAM), and then the universal adhesive (scotchbond) was applied. Composite cylinders were applied to the surfaces and photopolymerized.	-The shear strength of the universal adhesive (Scotchbond) is higher in the group prepared by bur and treated by etching and rinsing. In the etch-and-rinse procedure, the shear strength of the universal adhesive in the 4 W laser-prepared group was higher than that in the 5 W laser-prepared group. In addition, for the 4 W laser prepared group, the shear strength was higher when the etch-and-rinse surface treatment was performed compared to the self-etch surface treatment.
Jhingan P [20] *et al.* 2015	96 healthy human premolars	To compare and evaluate the shear strength of self-etch adhesives applied to cavities prepared by a diamond bur or Er,Cr:YSGG laser and the effect of prior acid etching on shear strength.	Er, Cr:YSGG 6W, 15Hz, 80% spray d'eau et 50% spray d'air	**Group1:** preparation with an Er,Cr:YSGG laser A1: Two-step self-etching adhesive for surface treatment (Clearfil SE Prime and Bond) 1b: Phosphoric acid 40% + Self-etching adhesive in two steps for surface treatment (Clearfil SE Prime and Bond) 1c: Phosphoric acid 40% + Universal adhesive (Clearfil S3) **Group 2:** Bur preparation with the same distribution of subgroups as group 1 Then all specimens were restored with a flowable composite (APX Flow).	-Adhesion is higher in the laser-prepared group ≫ than in the bur groups regardless of the type of adhesive used Shear strength: Highest with two-step SAM adhesive (Clearfil SE Bond) without prior acid etching -Lowest with the same adhesive but with acid etching.

4.1. Erbium Lasers

Erbium lasers are long wavelength lasers and are versatile. Indeed, they allow working mainly on hard tissue but also on soft tissue [6].

4.1.1. The Er:YAG Laser

The Er:YAG laser uses a solid-state active medium of yttrium and aluminum garnet doped with Erbium ions (Er^{3+}). The Er:YAG laser operates via an optical pumping system characterized by a luminous flash corresponding to an absorption band of the Erbium ion (Er^{3+}). It has a wavelength of 2940 nm corresponding to the absorption peak of water but also of hydroxyapatite. This results in a very good absorption by enamel, dentin and soft tissues. The Er:YAG laser is a very shallow penetrating laser (a few microns), which avoids heating of the peripheral tissues. It has photo-ablative and photo-acoustic effects [6].

The parameters of the Er:YAG laser are:

Operating mode: Pulsed.

Pulse duration: 50 to 200 µs.

Pulse frequency: 15 to 20 Hz.

Energy per pulse: 20 to 1500 mJ.

Average power: 0.3 to 20 W.

4.1.2. The Er,Cr:YSGG Laser

The Er, Cr:YSGG laser has as active medium a crystal of yttrium scandium gallium garnet doped with Erbium ions (Er^{3+}). The pumping system is also obtained by a light flash corresponding to an absorption band of the Erbium ion. As for its wavelength, it is 2780nm. The Er,Cr:YSGG and Er:YAG lasers have similar characteristics, they both have a high affinity for hydroxyapatite crystals and water. These two lasers have similar properties, however the Er,Cr:YSGG laser has a penetration of about 15 microns which is 3 times more than for the Er:YAG laser. This difference in penetration is explained by the fact that the wavelength of the Er,Cr:YSGG laser is slightly less absorbed by water at 2780 nm than the wavelength of the Er:YAG laser which operates in the water absorption peak; the difference in absorption coefficients leads to a difference in the penetration depths of the two Erbium laser wavelengths in the dental tissues [21].

4.2. Effect of Erbium Lasers on Dental Surfaces

Cavity preparation with the Er:YAG laser instead of conventional rotary instruments results in changes in the chemical composition of the treated substrate by increasing the amount of calcium ions in laser-prepared cavities compared to those prepared with a conventional method of drilling. This change may be related to the vaporization of water and organic components, which increases the percentage of mineral content in the dentin substrate [22].

4.3. Conditioning of Dental Surfaces with Erbium Lasers

In restorative dentistry, Erbium lasers can be used not only for cavity preparation but also for the treatment of dental surfaces intended for bonding, by modifying the laser parameters (power, energy, pulse duration, frequency). Indeed, the Er,YAG laser can be used for cavity preparation at 200 mJ, 20 Hz and for surface treatment of dentin at 80 mJ, 10 Hz [10].

We classified the studies included in this review into:

- Comparative studies between laser-prepared cavities and those prepared with a rotary bur.
- Comparative studies between different adhesive systems (SAM and M&R) and universal systems.
- Studies dealing with the pretreatment of dental surfaces prepared with Er:YAG and Er,Cr:YSGG lasers.

4.3.1. Comparison of Cavities Prepared with Er:YAG or Er,Cr:YSGG Laser and Those Prepared with a Rotary Bur

1) Infiltration studies

Several studies have shown that cavity preparation with diamond bur followed by acid treatment of the enamel surface and application of an all-in-one adhesive system had the lowest infiltration values compared to laser prepared surfaces [1] [12] [23] [24] [25]. However, other studies have shown that there was no statistically significant difference in infiltration values between these two preparation methods [26] [27] [28] [29] [30].

2) Mechanical tests

Shadman *et al.* [19] found that the shear strength of dentin prepared with a rotary bur was higher than if it was prepared with a 4 W and 5 W laser. It is the changes in the hydroxyapatite with areas of carbonization, amides and proteins as well as decomposition and disproportion of minerals that causes more microcracks. The denatured matrix proteins thus prevent proper penetration of the adhesive into the collagen matrix, preventing the formation of a proper hybrid layer at the tooth/restorative interface thus decreasing the shear strength [20] [31] [32] [33]. A decrease in bond strength has been shown on surfaces prepared with the Er:YAG laser (2 Hz, 300 mJ for enamel preparation, 250 mJ for dentin preparation) following the formation of a laser-modified layer [20].

However, with the Er,Cr:YSGG laser "6 W, 15 Hz, 80% water spray and 50% air spray" the shear strength is significantly higher than with bur preparations. This could be due to the irregularities and interlocking of the laser-irradiated hard tissue, which increases the contact surface and improves the bonding of the resin to the prepared tooth surface. In addition, laser irradiation creates a surface free of dentin sludge, with open dentin tubules that allow infiltration of the adhesive resin into the tubules to form bonds between the dentin surfaces and the resin, making the surface more favorable for adhesion [10] [20].

Other studies have shown no significant difference in bond strength between the two preparation techniques (laser/diamond bur) when a 35% phosphoric acid etch is used on the dentin surface [12] [34] [35].

3) Evaluation of the thickness of the hybrid layer

According to Kallis *et al.* [17], cavity preparation with the Er,YAG laser "3.75 W, 15 Hz, 250 mJ, water spray 20 ml/min, QSP mode" produces a rough dentin surface, not demineralized but with open dentin tubules, which can improve micromechanical retention. In contrast, in bur-prepared dentin, the surface is smoother, and the dentinal tubules are covered with dentinal sludge that prevents resin infiltration. These morphological characteristics may explain the greater thickness of the hybrid layers formed in laser-treated surfaces.

However, other studies using a "126 mj and 180 mj" Er:YAG laser have reported low laser efficacy for the preparation of dental surfaces [36] [37]. These contradictions can be attributed to various parameters such as different laser irradiation parameters, dental substrates, experimental design, methodology, etc.

4.3.2. Choice of Adhesive for Cavities Prepared with ER:YAG and ER, CR:YSGG Lasers

The universal adhesive containing MDP improves the bonding quality, and this is due to the ability of 10-MDPmonomer to create a chemical bond with hydroxyapatite resulting in the formation of a durable nanolayer and consequently an increase in mechanical strength [10]. The universal adhesive in M&R mode significantly increases the adhesion values to laser-irradiated dentin compared to the universal adhesive used in self-etch mode [38] [39]. In fact, the shear strength of laser-prepared dentin increases when surface treatment with M&R adhesive is performed [19].

Surface treatment with Er,Cr:YSGG laser irradiation prior to bonding with a self-etching adhesive system (Clearfil SE Bond) significantly increases the bond to eroded dentin [3]. Laser irradiation removes the eroded dentin layer, revealing a dent in surface that is more favorable for adhesion, without adversely affecting the dentin substrate [33] [40] [41].

The use of the M&R adhesive after Er:YAG laser preparation allows for a greater hybrid layer thickness than those treated with the self-etching adhesive [17]. However, the laser-prepared surfaces showed an increase in calcium and phosphate ions and a reduction in carbonate and water after thermal effects and crystallographic changes [18].

The carboxyl groups in the self-etching adhesive can chemically bind to hydroxyapatite and calcium and thus form stable calcium salts that enhance resin adhesion through the formation of strong ionic interactions between the substrate and the adhesive layer [42].

Comparison between self-etching systems

Cavities prepared with the Er:YAG laser at 490 mJ and 15 Hz showed that the tensile strength with a HEMA-containing adhesive was better than that with an adhesive without HEMA [11]. This is because the hydrophilic nature of HEMA promotes adhesion, improves wetting of the dentin and thus the bond strength. The better bond strength obtained with the HEMA-rich and ethanol-water-based self-etch adhesiveskept exposed collagen moist and does not collapse as much as air-dried dentin [43].

In addition, moist dentin may provide a more porous collagen network, allowing greater infiltration of adhesive monomers than on surfaces that are air-dried and in which the collagen collapses.

4.3.3. Pre-Treatment of Dental Surfaces Prepared with ER:YAG and ER, CR:YSGG Lasers

According to Chen M.L *et al.* [13], pretreatment with phosphoric acid or low-frequency Er:YAG laser irradiation "150 mJ; 10 Hz; short-pulse mode (SP, 300 µs); average power of 1.5 W; 19.10 J/cm^2 energy delivered/pulse;10 ml/min water spray" significantly improved the bond strength between self-etching adhesives and laser-prepared dentin "P = 4 W, Pulse duration = 100 µs, E = 200 mJ, F = 20 Hz, Energy density: 25.46 J/cm^2".

However, in the study by Ceballo *et al.* [37], laser preparation of dental surfaces combined with 35% phosphoric acid etching resulted in decreased shear strength values for a two-step total-etch adhesive. Their results also demonstrated that 35% phosphoric acid can only remove the surface of the laser-modified dentin layer, leaving partially denatured collagen fibrils that likely interfere with adhesive resin infiltration.

Preconditioning with phosphoric acid or phosphoric acid followed by sodium hypochlorite increases the bonding strength of the composite resin to the enamel and dentin prepared with an Er,Cr:YSGG laser [15]. This is due to the ability of phosphoric acid and/or sodium hypochlorite to remove the denatured dentin layer produced by the laser irradiation resulting in the opening of the dentinal tubules which subsequently facilitates the infiltration of the adhesive resin. However, the application of sodium hypochlorite after the acid etches dissolves not only the collagen in the heat-denatured dentin, but also the collagen in the healthy dentin directly underneath the denatured layer. Excessive pretreatment of the laser-prepared dentin could induce embrittlement of the hybrid layer at the adhesive interface and thus decrease the bond strength values [15].

According to Jhingan *et al.* [20], pre-etching of Er,Cr:YSGG laser-prepared tooth surfaces with phosphoric acid has a negative effect on the shear strength of self-etching adhesives.

This can be explained by the increased loss of calcium from the collagen network on the conditioned surface due to the strongly acidic action of phosphoric acid (pH = 0.5 to 1), resulting in a decrease in chemical bonds between the tooth surface and the self-etching adhesive.

In contrast to these results, Ergücü *et al.* [44] showed that surface treatment with an acid primer or phosphoric acid after laser preparation of the dentin significantly increased the adhesion values by removing the laser irradiation modified dentin layer that appeared to be resistant to acid attack [45].

5. Conclusions

In conclusion, laser treatment has no negative effect on the bonding performance of adhesion. Several factors can explain the difference in results between studies in chemical treatment of laser-prepared tooth surfaces, such as:

- The type of laser used used Er:YAG or Er,Cr:YSGG;
- The parameters of the laser device: energy, frequency, application mode;
- The type of adhesive system used: SAM, M&R or universal.

There is currently no consensus on the parameters of the lasers and adhesive systems to be used. Future high-quality studies could provide universal protocols.

Conflicts of Interest

The authors declare no conflicts of interest.

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