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The effect of pulsed Er,Cr:YSGG laser scanning on the adhesion strength of lithium disilicate to tooth dentin

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ABSTRACT

This study examined how Er,Cr:YSGG laser surface conditioning affected the adhesion of lithium disilicate ceramic to the dentin tooth structure. Forty samples were divided into four groups (n=10). The first group was untreated, whereas the second was etched with hydrofluoric acid. The third group was treated for 2 minutes with a 7 W, 25 Hz Er,Cr:YSGG laser. The fourth group received the same Er,Cr:YSGG laser treatment at 5 W. The untreated group had the lowest shear bond scores. Laser-irradiated Group 3 at 7 W had a higher maximum shear bond strength than the hydrofluoric acid-etched group. The laser-irradiated groups also had a more uniform, non-invasive surface roughness pattern. The samples were tested by atomic force microscopy, scanning electron microscopy, and a universal shear bond testing machine. Surface treatment with the Er,Cr:YSSG laser at 7 W improves lithium disilicate ceramic adhesion to dentin. The laser outperforms hydrofluoric acid as the gold standard.

Keywords: Laser, Dental ceramic, Er,CR:YSGG

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INTRODUCTION

The field of restorative dentistry has witnessed a notable increase in the development of ceramic materials with excellent esthetic qualities and high mechanical strength. This advancement can be attributed to the continuous evolution of dental technology and the growing demand for all-ceramic restorations.[1,2] Recently, aesthetic high-durability lithium disilicate glass ceramics (LDGC) have been developed and designed for pressing methods. These ceramics exhibit exceptional mechanical qualities.[3] They bridge the gap between synthetic and realistic aesthetics while performing an essential function in oral rehabilitation.[4,5] For stronger bonds between the ceramic and luting material, silane should be used on glasses type of ceramics before etching to produce a siloxane network with silica in the ceramic surface; silane coupling agents can achieve appropriate bonding characteristics.[6,7]

Surface treatment of dental ceramics promotes the bonding between the restoration and the dental structure by changing the ceramic's internal surface to create micro-porosities and increasing the surface area for bonding. There are different methods to treat lithium disilicate ceramic surfaces, the most common of which are etched with hydrofluoric acid and sandblasting. Regarding preparing the intaglio surface of glass ceramics, etching with hydrofluoric acid is considered the gold standard.[8,9] The crystalline structures within a ceramic material are exposed due to the use of hydrofluoric acid. The acid reveals the elongated crystals of lithium disilicate ceramic by dissolving and removing the glassy matrix. This, in turn, forms irregularities, peaks, and valleys on the surface. If the acid etch concentration and etching time are increased beyond what the manufacturer advises, the ceramic's nature may be altered, causing surface defects, grooves, and cracks.[10]

Numerous studies have employed various laser types (CO_2, Nd:YAG, and Er:YAG) to modify the internal surface of ceramics, aiming to augment their surface characteristics and improve their adhesion to the tooth structure. However, none of these studies achieved bonding enhancements that surpass the etching effect of hydrofluoric acid or yielded positive outcomes when employing specific parameters.[11,12] Nowadays, the Er,Cr:YSGG laser has won favor for its ability to ablate hard dental tissues and its applicability in various therapies for soft tissue. Because hard tissues and water easily absorb it, lasers that belong to the erbium family, such as the Er,Cr:YSGG, have negligible thermal impacts on the tissues close to them. In addition, they have non-invasive effects and do not cause any pain. Furthermore, applying Er,Cr:YSGG laser for surface conditioning has an antimicrobial effect. However, the effects of laser treatment can vary depending on several factors, including the exposure time, the beam's intensity, the distance between the specimen and the laser, and the type of bonding system utilized.[13]

The Er,Cr:YSGG laser, which utilizes the principle of microexplosion during tissue ablation, is responsible for generating both microscopic and macroscopic effects. Additionally, Er,Cr:YSGG lasers with a pulse duration of 60 μs have been successfully utilized to condition the surface of ceramics. Based on the current evidence, it is apparent that additional elucidation is necessary regarding the involvement of Er,Cr:YSGG in the surface conditioning of the lithium disilicate.[14] Previous studies have utilized different power levels, yielding poor results and inducing a lower or compromised degree of surface roughness that does not improve bonding strength.

In the present work, a pulsed Er,Cr:YSGG laser (2.78 μm) has been used to irradiate the lithium disilicate indirect restoration to increase its adhesion to tooth dentin. The optimal parameters required to perform the bonding process have been determined for different power settings. The optimized bond strength for the lithium disilicate restoration (E-max) was found at a 7-watt power level, surpassing the results of acid etching. No adverse changes on the ceramic's surface were observed. Moreover, the surface inspection was conducted by atomic force microscopy and scanning electron microscopy. The experiments were accompanied by irradiation of the ceramic surface in a sweeping motion, and the laser tips were positioned perpendicularly to the samples and fixed at one millimeter for the optimum irradiation setup.

MATERIALS AND METHODS

Ceramic Sample Preparation

A total of forty IPS E-max cylinders measuring 4 mm in diameter and height (4x4x4 mm), composed of lithium disilicate glass-ceramic (Ivoclar Vivadent, Schaan, Liechtenstein), were heat-pressed according to the manufacturer's instructions. No glazing procedures were performed on the sample surfaces. The surfaces of the samples were smoothed and polished with silicon carbide paper of 1200 grit using a polishing machine under water chilling. Subsequently, the samples were placed in an ultrasonic device for 10 minutes to eliminate any impurities or detritus before surface conditioning and air drying. At this point, the samples were randomly assigned to four groups (n=10) as follows:

Group 1 (control group): No surface treatment was applied in this group.

Group 2: The samples' surfaces were etched for 90 seconds with 9.5% hydrofluoric acid (Bisco Porcelain etchant, USA) and cleansed for 90 seconds to remove any remaining acid. Then, the samples were subsequently air-dried.

Group 3: The ceramic surfaces were treated with Er,Cr:YSGG laser irradiation (Millennium Biolase Technology Inc., San Clement, CA, USA) using the following laser parameters under air/water spray: Configuration: power = 7 W, wavelength = 2.78 μm, 25 Hz Water/Air 50/50%. The laser conducting tip (MZ 6 μm) was positioned perpendicular to the sample surfaces, one millimeter distant, with an irradiation time of two minutes. The samples were then placed in an ultrasonic device for 5 minutes and then air-dried.

Group 4: The ceramic surfaces were treated with Er,Cr:YSGG laser irradiation (Millennium Biolase Technology Inc., San Clement, CA, USA) under air/water discharge with the following laser parameters: power setting = 5 W, wavelength = 2.78 μm, 25 Hz Water/Air 50/50%. The laser conducting tip (MZ 6 μm) was positioned perpendicular to the sample surfaces, one millimeter distant, with an irradiation time of two minutes. The samples were then placed in an ultrasonic device for 5 minutes and then air-dried.

Dentin Specimen Preparation

Forty third molar teeth were collected from individuals planning to have them extracted, with exclusion criteria involving teeth with decay or fillings. The occlusal surface of all molars was abraded using 800-grit silicon carbide paper and water cooling in a polishing machine until dentin was exposed, as illustrated in Figure 1. Then, the teeth were positioned in a custom-made mold containing self-cured acrylic resin and aligned using a dental surveyor. Microscopic examination of the dentin surface verified the absence of a pulp cavity. To ensure a uniform bond between the lithium disilicate samples and tooth dentin, a dentin bonding surface of 4 mm diameter was prepared using a dental wheel bur (4 mm diameter) (SWS, Izmir, Turkey).[15]

Bonding Procedures

The dentin specimens embedded in the acrylic resin were conditioned and prepared for cementation following the manufacturer's instructions. Each dentin surface underwent a 15-second treatment with 37% phosphoric acid, followed by a thorough 15-second water rinse. Subsequently, the surface was temporarily air-dried. Dentin adhesive was applied and light-cured on the etched dentin for 20 seconds using a light-emitting diode (Guilin, Woodpecker Medical Instrument, China) with an energy output of 1600 mW/cm^2.

Each glass-ceramic sample underwent silanization (Bisco, Porcelain silane, US). The silane was applied to all desiccated sample surfaces for 60 seconds and dried using an air stream. Then, the ceramic samples were bonded to the adhesive-coated dentin using a dual-cured resin cement (Bisco porcelain, Dual-cured cementing agent, United States). The resin cement was light-cured at the interface between the glass-ceramic and dentin specimens for 40 seconds.

Finally, the samples were submerged in distilled water at 37 degrees Celsius for 24 hours. After this, the samples underwent a shearing force applied by a chisel-shaped blade at the ceramic-tooth interface to measure the bond strength of lithium disilicate glass-ceramic to the dentin tooth structure. Using a digital stereomicroscope (Euromex Microscope, Reflection/Transmission, Holland)

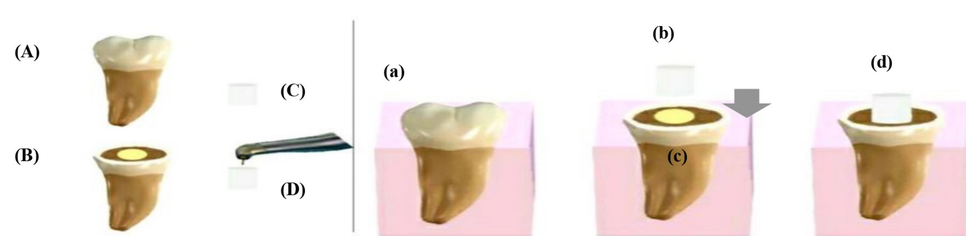


Figure 1. Ceramics, tooth preparation scheme: (A) Sound third molar tooth; (B) Prepared molar tooth; (C) Lithium disilicate cylinder; (D) Laser irradiated lithium disilicate cylinder; (a) Sound third molar tooth embedded in acrylic resin; (b) Lithium disilicate cylinder; (c) Prepared tooth for cementation process; (d) Lithium disilicate cylinder cemented to tooth dentin.

at a magnification of 4X, the debonded surface patterns (tooth, ceramic) were determined following the classification system below:

Failure modes were categorized into:[16]

1. Adhesive failure: if more than 75% of the lithium disilicate cylinder surface is visible.
2. Cohesive failure: if more than 75% of the lithium disilicate cylinder surface is covered with resin.
3. Mixed failure: if 50% of the lithium disilicate cylinder surface is covered with resin cement or is visible.

RESULTS

The shearing bonding strength (SBS) values were subjected to statistical evaluation using a one-way ANOVA test, and these values were shown to have a normal distribution by the Shapiro-Wilk test. The impact of ceramic bonding surface treatments on their SBS was investigated across four different study groups, with Table 1 presenting the determined SBS values. Compared to all experimental groups, the values of the control group's SBS were considerably lower than those of all experimental groups, as depicted in Figure 7. Group 3 (ECL 7 W) exhibited the highest SBS values at (5.84 ± 2.03 MPa).

Group 2, the hydrofluoric acid-etched (HFA) group, yielded results of (4.97 ± 1.45 MPa), while Group 3 (ECL 7 W) had results that were (5.84 ± 2.03 MPa). Both groups showed comparable outcomes (no significant difference). Compared to Group 2 (HFA), the SBS of specimens subjected to ECL power 5 W surface treatment for bonding was substantially lower at (3.84 ± 0.51 MPa). Atomic force microscopy (AFM) and scanning electron microscopy (SEM) illustrated the impact of various surface treatments on the ceramic surface. Following treatment with HFA, microscopic and macroscopic abnormalities were observed in exposed LD crystals. Specimens treated with an Er,Cr:YSGG laser displayed equally distributed irregularities, with broad peaks in Group 3 (power 7 W) and a pointy one in Group 4 (power 5 W). In contrast to the HFA-treated samples, the laser-treated specimens exhibited a uniform bonding surface without defects, as shown in Figures 2, 3, 4, 5, and 6. The most prevalent failure mode was adhesive failure, as detailed in Table 2 and depicted in Figure 8.

Table 1. The descriptive and statistical test of the shear bond strength for the study groups.

Groups	Mean (MPa)	SD	Std. Error	P-Value
1-Group 1 (Control)	0.87	0.36	0.52	0.001HS
2-Group 2 (HF)	4.97	1.45		
3-Group 3 (Er;Cr:YSGG 7 W)	5.84	2.03		
4-Group 4 (Er;Cr:YSGG 5 W)	3.84	0.51		

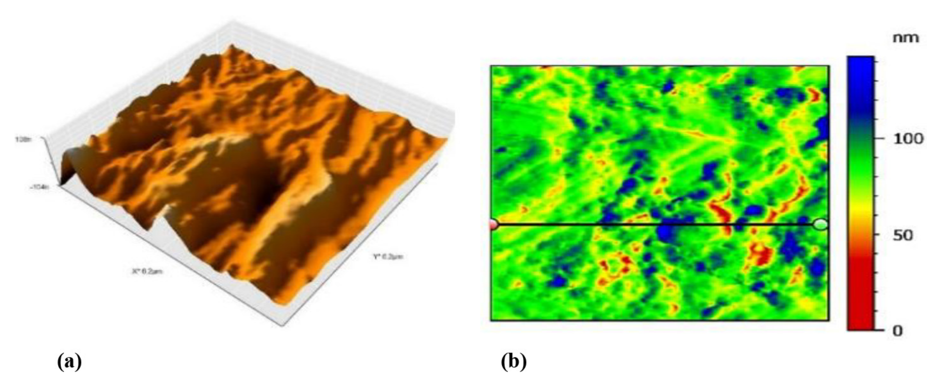
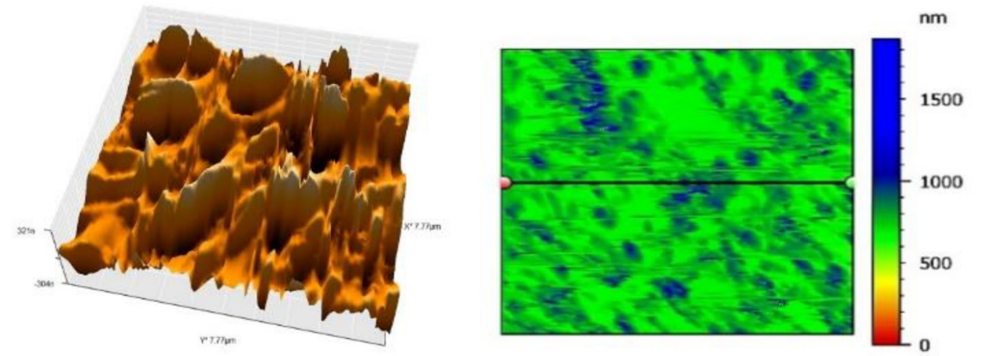
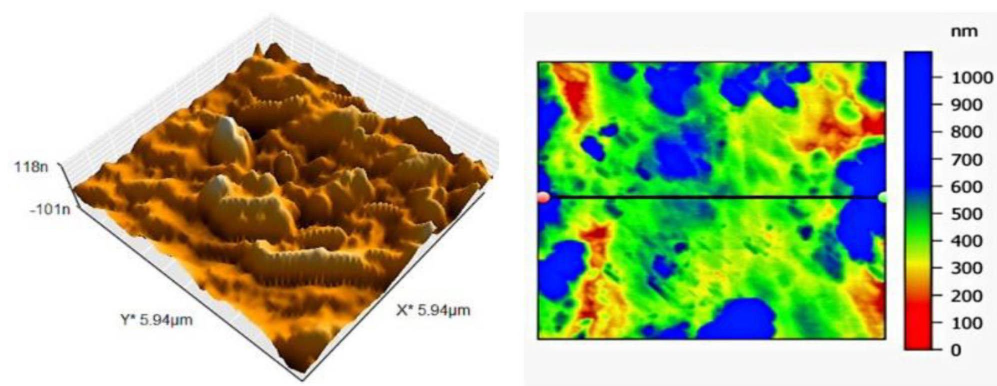


Figure 2. Atomic force microscopy (AFM) images of lithium disilicate cylinders (untreated, Group 1): (a) 3D; (b) pseudo-color view of the surface.



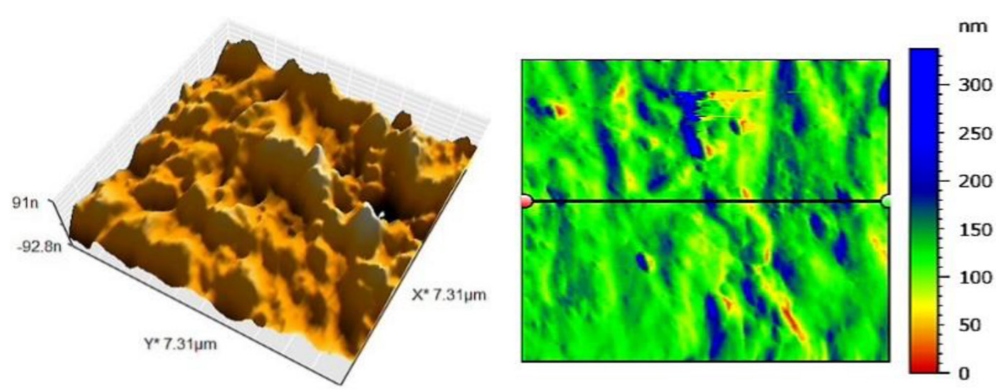
(a) (b)

Figure 3. Atomic force microscopy (AFM) images of lithium disilicate cylinders (acid etched, Group 2): (a) 3D; (b) pseudo-color view of the surface.



(a) (b)

Figure 4. Atomic force microscopy (AFM) images of lithium disilicate cylinders (laser irradiated sample power 7 W, Group 3): (a) 3D; (b) pseudo-color view of the surface.



(a) (b)

Figure 5. Atomic force microscopy (AFM) images of lithium disilicate cylinders (laser irradiated sample power 5 W, Group 4): (a) 3D; (b) pseudo-color view of the surface.

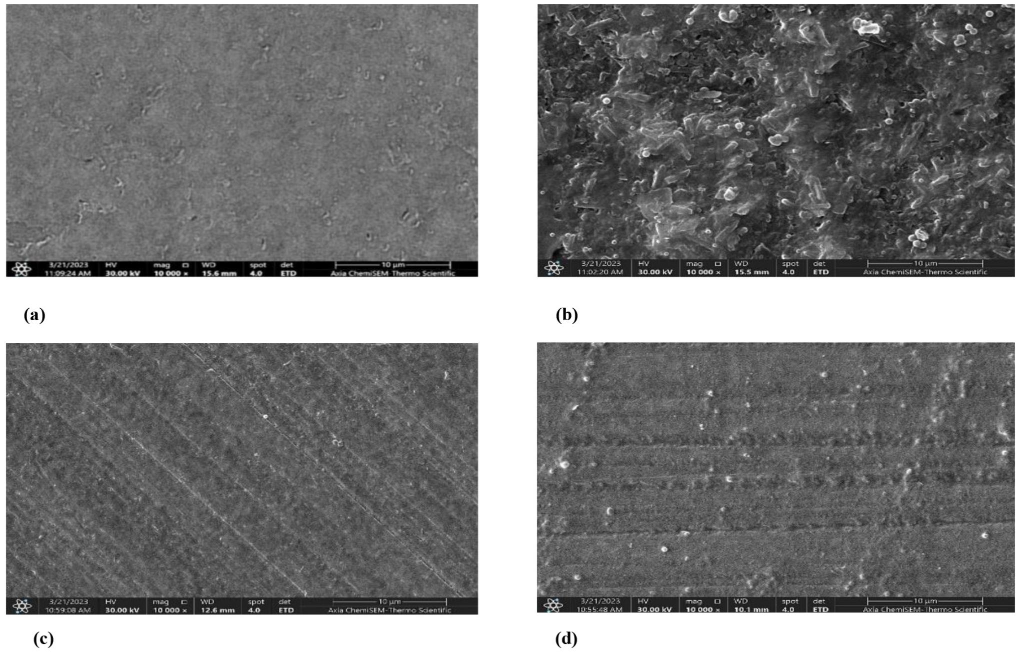


Figure 6. Scanning electron microscopy (SEM) images of lithium disilicate cylinders at 10000X: (a) SEM of untreated sample, Group 1; (b) SEM of acid etched sample, Group 2; (c) SEM of laser irradiated sample power 5 W, Group 4; (d) SEM of laser irradiated sample power 7 W, Group 3.

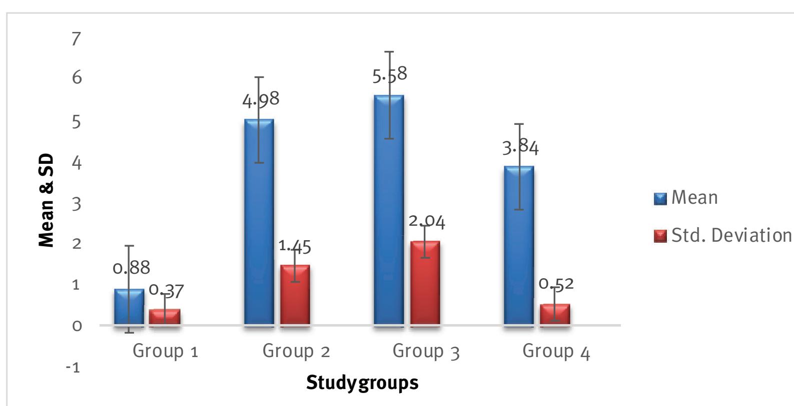


Figure 7. Means and standard deviation of the shear bond strength (MPa) of the study groups.

Table 2. The predominance of the modes of failure.

Modes of failures	Group (1)		Group (2)		Group (3)		Group (4)	
1-Adhesive failure	10	100%	7	70%	6	60%	8	80%
2-Cohesive failure	-	0%	1	10%	2	20%	-	0%
3-Mixed failure	-	0%	2	20%	2	20%	2	20%

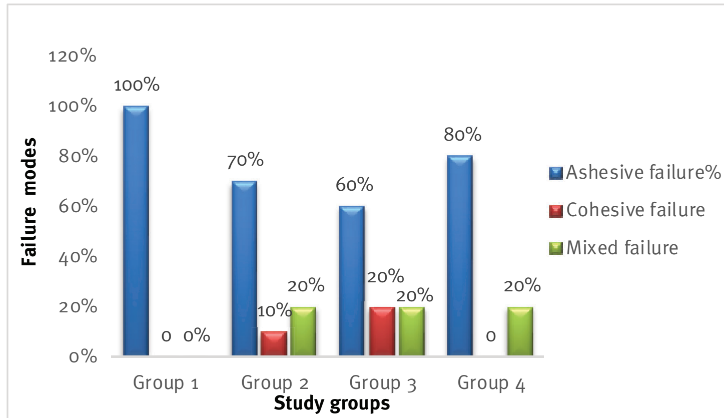


Figure 8. Failure modes of the study groups.

DISCUSSION

Achieving the most effective adhesion and bonding of ceramics intended for restorative applications necessitates proper preparation of the inner surfaces. Multiple methodologies, such as grinding, employing rotary tools, and utilizing airborne particles (specifically Al_2O_3) for abrasion, can facilitate bonding.[17] However, these techniques may have potentially detrimental drawbacks, leading to irreversible alterations to the surface of the ceramic material. The acid etching process involving hydrofluoric acid (HF) is another method, but its effectiveness has certain limitations. For instance, it can potentially dissolve the glaze layer and target the glassy phase of ceramics, causing surface dissolution to a few micrometers in depth.[18] Hydrofluoric acid usage in the oral cavity poses challenges due to its potential harm to bodily tissues. Previous studies indicate that laser irradiation is an alternative method for conditioning ceramics.[11]

The laser's ability to remove and modify hard dental tissues and its application in other soft tissue therapies have recently gained significant credibility. This approach is considered conservative, minimizing structure removal and making it a preferred method for dental procedures.[19,20] However, the choice of laser type and specific settings can significantly influence ceramic characteristics and behavior. Further investigation is needed to comprehensively understand the role of Er,Cr:YSGG in the surface conditioning of LD. Additionally, a lack of consensus exists regarding a standardized protocol for optimizing the power, treatment duration, and laser application frequency in ceramic conditioning.

The primary impact of a laser is the conversion of radiant light into heat, known as the thermo-mechanical effect. Consequently, the principal interaction between the material and the laser is the absorption of laser energy by the material's surface.[21,22] Ceramic material exhibits complete wavelength absorption of Er,Cr:YSGG laser (ECL). Previous investigations using varying power levels have yielded unsatisfactory outcomes, often focusing on assessing the bond strength between resin cement and ceramic materials. Given that lasers operate by surface ablation, this study primarily aims to evaluate the impact of Er,Cr:YSGG laser surface conditioning on LD ceramics, particularly exploring how modifications to laser parameters may result in improved bond strength compared to the conventional application of HF acid.

The experimental results suggest that the accuracy of etching achieved by the Er,Cr:YSGG laser (ECL) is influenced by the proximity of the laser's focal point to the treated surface. It was established that the most effective distances for Er,Cr:YSGG were 1 mm to attain ideal outcomes.[14] Previous research has indicated that using the Er,Cr:YSGG laser at power levels of (0.5 W, 1.5 W, 2.5 W) and a frequency of 10 Hz demonstrated lower efficacy compared to the application of hydrofluoric acid.[23,24] Tests to determine the optimal power for surface conditioning revealed that the ECL demonstrated superior results when utilizing higher power levels of 5 and 7 W. This choice was made due to the increased effectiveness observed in the surface conditioning of lithium disilicate ceramics when higher powers were employed. Importantly, using lasers for an extended duration leads to an augmentation in surface roughness. It was demonstrated that ceramics subjected to laser treatment over an extended period exhibited enhanced bonding strength.[25]

The Er,Cr:YSGG laser can remove particles through ablation, which involves microexplosions and vaporization. During vaporization, the internal pressure within the tissue gradually escalates until the inorganic material experiences a sudden and forceful disintegration before reaching its melting point. The ECL is employed to induce a regulated dispersion of atomized water droplets within a water/air spray to moisturize the surface of hard tissue in the context of applications related to hard tissue. The absorption of laser wavelength leads to the expansion of molecules and the subsequent ablation of hard tissue. Concurrently, the water in the spray fulfills the dual function of cooling and aiding in conditioning the targeted tissue.[19,26]

The study groups were exposed to Er,Cr:YSGG laser irradiation at 5 and 7 W power levels. Atomic force microscopy and scanning electron microscopy images indicated a favorable impact on surface topography compared to the control group. Furthermore, laser treatment was found to be an effective alternative to using hydrofluoric acid for surface treatment. The results of the laser-irradiated specimens at both power levels demonstrate a notable increase in shear bond strength compared to the control group. This observed improvement is statistically significant. The ECL group irradiated at 7 W exhibited a greater average bond strength than HF due to employing laser parameters (ECL) characterized by repeated applications with low frequency, high power, and extended duration. These parameters resulted in more efficacious augmentation of the bond integrity of ceramic specimens.

The surface roughness pattern significantly influences the shear bond, especially when it exhibits a uniform distribution and is characterized by several rounded peaks, facilitating the flow of resin cement into the minor irregularities on the surface.[26] Furthermore, the study revealed a positive correlation between the power and duration of the laser therapy and the mean bond strength. When conducting a comparative analysis between the findings of this study and those of Kursoglu et al. and Gokce et al., it is evident that the use of a 6 W laser for ceramic surface treatment, deemed ineffective by the mentioned studies, resulted in limited enhancement of bond strength between ceramic restoration and resin cement within a 60 s timeframe.[27] Conversely, this study demonstrates that prolonged laser exposure yielded improved ceramic topography and higher bond strength values. Additionally, the research conducted by Atomic Force Microscopy (AFM) revealed the presence of notable roughness patterns and surface imperfections that were comparable to or even beyond those detected in the group subjected to treatment with Hydrofluoric (HF) acid.[28]

Understanding the underlying causes of failure modes could achieve a more comprehensive comprehension of clinical limitations. The analysis of failure modes offers essential insights into the assessment of bonding quality. The current study examined the prevalence of cohesive and mixed failure types in Group 3 (7 W) subjected to laser treatment. Their occurrence was higher than the failure modes observed in the other groups. On the other hand, the prevailing failure mechanism seen in the control group was attributed to the adhesive type, indicating a reduced bond strength of 0.87 MPa. There was no observed link between the modes of failure and the bond strength values. Fractures characterized by adhesive failure had a higher frequency than other fracture types. Applying silane on the LD surface led to the establishment of hydrogen and predominant bonds between the ceramic and the resin cement. This phenomenon can account for the prevalence of adhesive failure mode, even in the HF and laser 7 W group, which exhibited substantial bond strength.[29,30] This outcome is consistent with a prior investigation conducted by Chaharom et al., wherein they asserted that the adhesive type exhibited the highest failure mode occurrence.[29]

CONCLUSION

Er,Cr:YSGG laser (ECL) irradiation of lithium disilicate surface increased the bonding surface area without defects, enhancing the micromechanical retention of the resin cement and dentin structure. Additionally, ECL irradiation of the ceramic surface with a power of 7 W and a frequency of 25 Hz resulted in a significant increase in shear bond strength with resin cement bonded to tooth dentin, exceeding the gold standard etching protocol of ceramics with hydrofluoric acid (HF).

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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No fund was received to conduct this study.

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