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Er:YAG Laser Versus Conventional Surface Treatment of Lithium Disilicate: In Vitro Study

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Abstract

Introduction: The high-power 2940 nm Er:YAG (erbium-doped yttrium aluminium garnet) laser increases the rough surface of lithium disilicate, increasing the bonding strength of ceramics when they are bonded to the tooth using resin matrix cement. This investigation aimed to compare the Er:YAG laser with the conventional surface treatment of lithium disilicate.

Methods: In this study, 50 lithium disilicate discs (5 mm diameter × 2 mm thickness) were divided into five groups (n = 10): Control group (CG) (10% hydrofluoric acid followed by 37% phosphoric acid), Group 1 (G1) (ER:YAG laser energy of 300 mJ/50 µs), Group 2 (G2) (Er:YAG laser energy of 400 mJ/50 µs), Group 3 (G3) (Er:YAG laser energy of 500 mJ/50 µs), and Group 4 (G4) (10% hydrofluoric acid, Er:YAG laser energy of 500 mJ/50 µs). After completing the surface treatments, 6 mm high Tygon was fixed and filled with self-adhesive dual resin cement (SET PP SDI Limited, Victoria, Australia). The samples were stored for 24 hours and subjected to shear tests until structural failure.

Results: ANOVA analysis found no statistically significant difference between the groups analyzed ($P = 0.0689$). G2 had the highest bond strength with 12.6 ± 3.2 MPa, while G1 had the lowest with 9.5 ± 2.2 MPa, followed by the CG 9.8 ± 3.2. It was observed that with higher laser irradiation power, the adhesive strength decreased, as evidenced in G3 with 11.6 ± 1.9 MPa.

Conclusion: The radiation power of 400 mJ, frequency of 20 Hz, and pulse duration of 50 µs improved the bond strength between lithium disilicate and dual resin cement. However, the group that obtained the lowest strength was Group 3, with a laser energy of 500 mJ/50 µs, generating highly expulsive zones in lithium disilicate.

Keywords: Erbium YAG; Lithium disilicate; Shear bond strength.

Introduction

Nowadays, patients request highly esthetic restorations with optical characteristics like those of dental tissue, with less invasive preparations and with high resistance.[1] The material that meets these clinical characteristics is lithium disilicate, which has excellent mechanical and optical properties similar to dental pieces, allowing the manufacture of veneers, inlays, and stratified and monolithic crowns.[2-4] This compound is characterized by its excellent esthetics and durability in the final restoration.[5,6]

For the cementation process, the thickness of the restoration and its curing methods (light-cured vs. dual-cured) must be considered since the choice of cement depends on these aspects.[7] Within the cementation protocol, many authors consider it necessary to perform a surface treatment for lithium disilicate consisting of 10% hydrofluoric acid etching.[8] After this, salts are generated, which must be eliminated by means of an ultrasonic bath for 5 minutes or the application of weak acids, with the most commonly used one being 37% phosphoric acid.[9] After this process, apply silane[10] and finally apply a cement.[11,12] This entire process is considered the gold standard for treating lithium disilicate-based ceramics.[13]

Nowadays, most clinicians use the gold standard protocol in their restorations since it has very good results, but some studies have evaluated the use of Er:YAG lasers, which would increase the adhesive strength between resin cement and lithium disilicate. All this is done through the process of "water-mediated thermomechanical ablation," creating microscopic porosities by vaporization and micro-explosions that occur on the surface, improving the surface energy of the ceramic and facilitating the absorption of silane.[13,14] The high-power 2940 nm Er:YAG laser increases the roughness of the surface of lithium disilicate, increasing the bonding strength of the ceramics when they are bonded to the tooth using resin matrix cement.[14,15]

The mechanism of action of the laser depends on a thermomechanical effect mediated by water. A laser system

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with a wavelength of 2940 nm produces the vaporization of these molecules by thermal softening, thermal ablation and photo-ablation.[16-18] Due to this mechanism of action, the Er:YAG laser could be considered as an alternative surface treatment for lithium disilicate-based ceramics in dentistry.[19-22] First, an electromagnetic spectrum is produced by increasing the temperature to the degree of fusion and evaporation, causing microexplosions in the ceramic. Other investigations have applied the Er:YAG laser with 300 mJ/400 mJ at 20 Hz/50 µs pulses, obtaining hollow and dispersed irregular concave structures. However, one study mentioned that the application of 500 mJ at 20 Hz/50 µs pulses produces crater-shaped structures, which would improve adhesion strength. It is important to know which methods are best for treating dental materials, especially lithium disilicate, since it is one of the compounds most frequently used by clinicians today due to its excellent optical and mechanical properties. The use of a laser method instead of a conventional method would improve clinical times and increase adhesive strength.[21,23,24] While hydrofluoric acid is used as a cleaning agent in crowns, veneers, and bridges, increasing the adhesive strength of lithium disilicate, the most common error is its handling, as it can cause injuries to the patient's mucosa or even to the operator's face or hands due to improper handling. Because of this, a safe alternative would be the use of the Er:YAG laser; however, to date, there have been no standardized parameters for its use for this treatment. The purpose of this investigation was to compare the Er:YAG laser with the conventional surface treatment of lithium disilicate.

Methods

The present *in vitro* study followed the standards required by the Ethics Committee of the Universidad Científica Del Sur.

Sample Preparation

A pilot study was conducted to determine the total number of the current sample, which resulted in 10 samples per group. A total of 50 lithium disilicate discs with a diameter of 5 mm and a height of 2 mm were manufactured (E-max Press MT A1 Ivoclar Vivadent, AG Schaan Liechtenstein).[25] The discs were then placed in a polyvinyl chloride tube (PVC) which was 26 mm by 10 mm high, filled with pink self-curing acrylic.[26] The high-power laser system used was a 2940 nm Er:YAG (Pluser/doctor smile/Vicenza, Italy).

The samples were randomly divided into 5 groups (n = 10), using different surface treatments with Er:YAG laser at different powers and conventional surface treatment, which will be described below (Table 1).

Table 1. Laser Parameters: Power Density and Spot Size Per Group

Group	Energy	Power	Frequency	Pulse	Time
G1	300 mJ	6.0 W	20 Hz	50 µs	20 s
G2	400 mJ	8.0 W	20 Hz	50 µs	20 s
G3	500 mJ	10.0 W	20 Hz	50 µs	20 s

Control group (CG): The surface was treated with 10% hydrofluoric acid for 20 seconds, washed with water for 30 seconds, and dried with air. Phosphoric acid at 37% was applied for 60 seconds (to remove salts formed by the chemical reaction of etching with hydrofluoric acid) and was then washed with a water jet for 30 seconds and dried.

Group 1 (G1): The Er:YAG 2940 nm laser was used with a window handpiece, with a pulse of 50 µs, power of 6 W, energy of 300 mJ, frequency of 20 Hz, peak power of 6000 W, water flow of 60%, and focal spot of 200 µm. Finally, the laser was positioned at 7 mm, performing two vertical and horizontal manual scans for 20 seconds over the entire surface of the ceramic, which was subsequently washed with water for 180 seconds and dried for 15 seconds.[27-29]

Group 2 (G2): The same laser and pulse as in group 1 were used, varying the power to 8 W, energy to 400 mJ, frequency to 20 Hz, and peak power to 8000 W. The laser tip and scanning system were positioned according to the indications for G1.

Group 3 (G3): The same laser and pulse as in group 1 were used, varying the power to 10 W, energy to 500 mJ, frequency to 20 Hz, and peak power to 10,000 W. A window handpiece with a focal point of 7 mm was used, and a uniform vertical and horizontal sweep was performed on the ceramic surface for 20 seconds according to the indications of G1.

Group 4 (G4): The combination of the surface treatment of the CG (conventional acid treatment) and G3 (with the laser system) was used.

Studies have been carried out using a similar Er:YAG laser at energy levels of 300 mJ, 400 mJ, and 500 mJ to evaluate their effects on the adhesive strength between lithium disilicate and dental tissue.[23,28] However, no studies have been carried out between lithium disilicate and self-adhesive cement to identify the adhesive strength between both materials.

After surface treatments according to the study group, silane (Prosil FGM, Joinville, SC, Brazil) was applied with a microbrush over the entire surface of the discs (evaporation for 60 seconds). Resin cement tygons with a diameter of 2 mm by 6 mm in height (SET PP SDI Limited, Victoria, Australia) with an automix tip were manufactured and handled according to the manufacturer's instructions. Photocuring was performed with an LED lamp with a light intensity of 1100 mW/cm2 (Elipar™ DeepCure-L 3M™ Oral Care, St. Paul, MN, USA) for 20 seconds. Finally, the plastic tubes (tygons) were removed after 10 minutes with a number 11 scalpel blade. All the samples were stored in distilled water at 37 °C for 24 hours (Table 2, Figure 1).

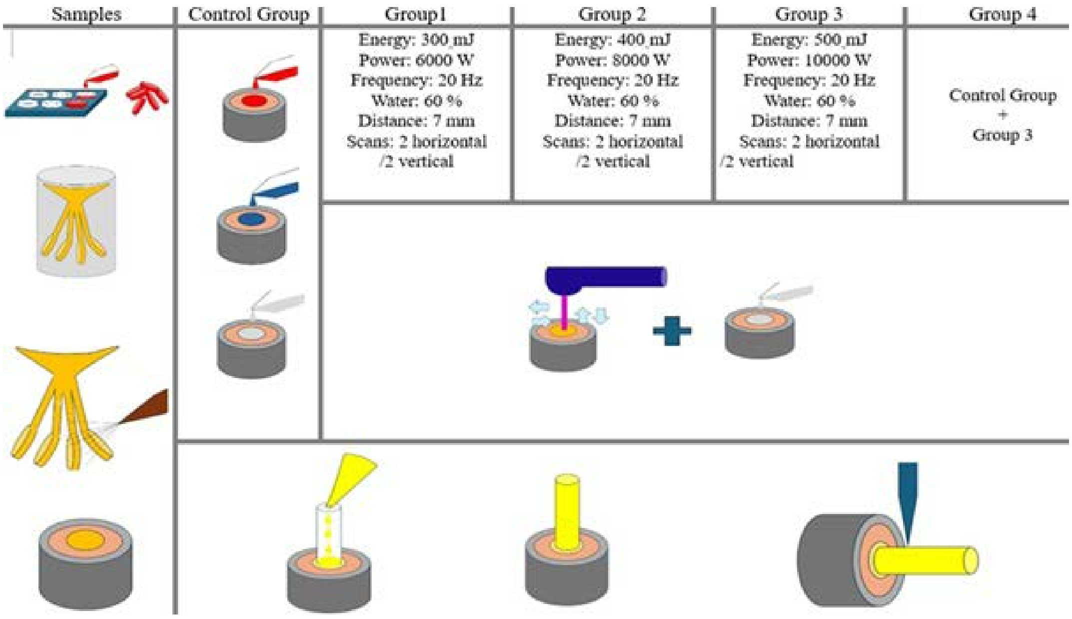

Figure 1. Sample Preparation Scheme

Table 2. of Material, Composition and Manufacturer. Please correct the word Pearls of shine to the correct word "Perlablast ®"

Material	Brand	Manufacturer	Lot
Lithium disilicate	IPS e.max press	Ivoclar	Z05DG4
Resin dual cement	SET PP SDI	FGM	1215888A
Silane	Monobond	Ivoclar	100523
Acrylic	Duralay	Reliance	110118
Coating	IPS® PressVEST	Ivoclar	WL 1830
Softening liquid	IPS e.max Press Invex	Ivoclar	CL 1830
Pearls of shine	Perlablast 125	Ivoclar	XLP 31467

After 24 hours, the shear bond strength (SBS) test was performed with the universal testing machine (LG-CMT-5L series 7419 Korea) to measure the adhesive strength with an initial load of 0.001 MPa, which was progressively increased until producing structural failure with a constant speed of 0.75 ± 0.25 mm/min.

After SBS testing, all the samples were examined by microscopy (Andonstar ADSM201, Shenzhen Andonstar Technology Co. Ltd., Shenzhen, Guangdong, China) at $1600\times$ magnification. Failures were classified as mixed, adhesive and cohesive.

Statistical Analysis

To determine the normality of the groups, the Shapiro-Wilk test was used. The results of the SBS test were analyzed using the ANOVA and Tukey tests, with a significance level of 5%. The statistical analyses were performed using SPSS version 29 (SPSS Inc., Armonk, NY, USA).

Results

The data presented normality and homogeneity of variance ($P > 0.05$). One-way ANOVA analysis showed that there were no statistical differences between the groups analyzed ($P = 0.0689$). The use of laser as a surface treatment in groups 2, 3 and 4 increased the SBS compared to the CG and G1 ($P < 0.05$).

G2 had the highest bond strength with 12.6 ± 3.2 MPa, while G1 had the lowest with 9.5 ± 2.2 MPa, followed by the CG (9.8 ± 3.2). It was observed that with higher laser irradiation power, the adhesive strength decreased, as evidenced in G3 with 11.6 ± 1.9 MPa. However, the application of acid etching in G4 improved the adhesive strength to 12.4 ± 3.9, without exceeding G2 (Table 3).

We examined the samples of each group with optical microscopy, finding the following characteristics: The lithium disilicate without surface treatment showed an area with few transverse irregularities with few porosities. The GC presented eroded areas in the form of craters. In G1, small areas of dispersed porosity were observed on the surface of the disilicate. In G2 and G3, a greater number of porosities were observed covering larger areas. In G4, porosities were observed throughout its extension, combined with areas of erosion. In relation to the SBS, G2 presented the highest adhesive resistance, with cohesive failures occurring at the cement level, while G3 and G4 had seven mixed and cohesive failures, respectively. Mixed failure prevailed in most of the groups (Figure 2).

Discussion

The SBS of the GC was similar to the surface treatment of G1, while G2 produced the highest SBS. G4 presented a decrease in SBS, which could be due to the expulsive surface roughness produced in this group. Likewise, G4 obtained SBS similar to that produced by G2, which could be due to the fact that the acid etching partly improved the

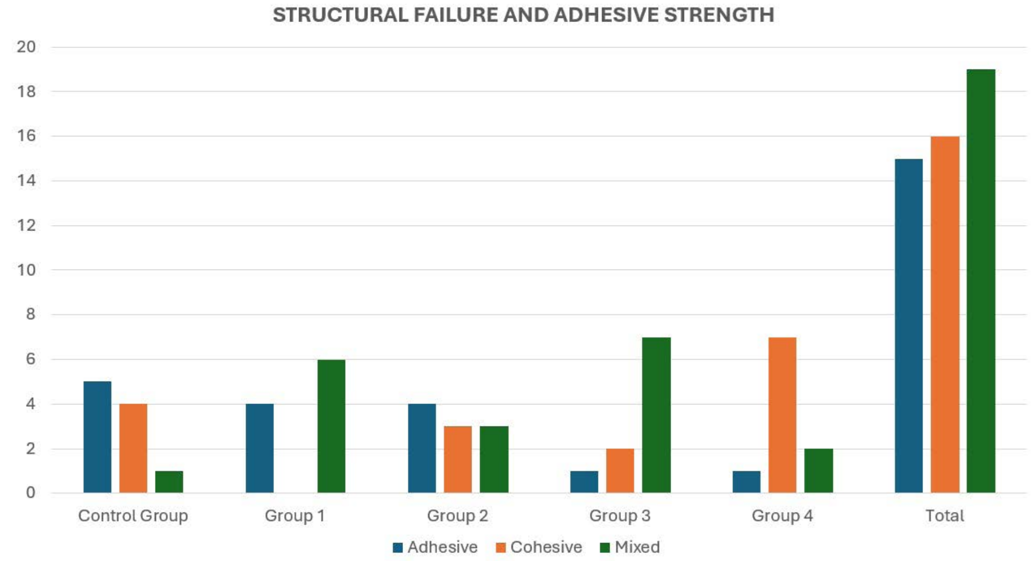

Figure 2. Structural Failure Mode and Adhesive Strength Chart

Table 3. Structural Failure Modes and Adhesive Strength

	Adhesive	Cohesive	Mixed	MPa
Control group	5	4	1	9.8 ± 3.2
Group 1	4	0	6	9.5 ± 2.2
Group 2	4	3	3	12.6 ± 3.2
Group 3	1	2	7	11.6 ± 1.9
Group 4	1	7	2	12.4 ± 3.9
Total of samples	15	16	19	

retention of the cement to the disilicate, even though the differences in resistance were not statistically significant.

Carek et al demonstrated that the objective of surface treatment is to create roughness inside the restorations based on lithium disilicate reinforced with zirconium. This is achieved by etching with hydrofluoric acid, sandblasting with 30 µm aluminum oxide, and an Er:YAG laser. The laser produces a major roughness and improves the micro retention of silane.[30] The results of this study confirm that the 2940 nm Er:YAG laser produces roughness on the surface of lithium disilicate, but they question the use of sandblasting on zirconium-reinforced lithium disilicate, which may create microcracks or fracture of the restoration.

El-Damanhoury et al reported that the formation of roughness by the ER:YAG laser is comparable to that formed by sandblasting and acid etching.[31] On the contrary, the present investigation showed that the use of laser energy of 400 mJ creates roughness that provides greater adhesive strength than acid etching.

The results of the present study support the statement of Maawadh et al[32] that the use of laser systems could be a potential alternative to conventional conditioning of lithium disilicate-based ceramics.[32] Abdel Sadek et al reported that laser irradiation improves marginal sealing by raising the bond strength due to the change in topography of the lithium disilicate.[33] The present work agrees that the use of a laser system increases the bond strength due to the roughness formed in lithium disilicate.

Dikicier et al observed that the combination of hydrofluoric acid and aluminum oxide sandblasting obtained greater bond strength with the Er:YAG laser, which did not produce a major difference in the changes in roughness.[34]

In their systematic review and meta-analysis on the application of a laser in surface treatments in ceramics, Nascimento et al concluded that the application of a laser to lithium disilicate-based ceramics generated a greater adhesive bond strength compared to conventional hydrofluoric acid etching.[35] However, the results of the present study are contrary to those of the study by Nascimento et al, who found better adhesive resistance with the use of a laser with an energy of 400 mJ.

The chemical etching produced by hydrofluoric acid in the vitreous matrix of the ceramic creates porosities, which aid in mechanical retention during the cementation process, while the Er:YAG laser has the ability to eliminate particles through the process of microexplosion and vaporization (ablation process).[23,28] This explains the results found in group 2, which generated better retention because the laser penetrated the vitreous matrix of the ceramic, causing good mechanical retention, while in group 3, by increasing the energy to 500 mJ, expulsive and non-retentive retentions were produced, which affected the adhesive strength. In contrast, in group 4, both protocols were experimentally used, and it was found that using acid etching in combination with an Er:YAG laser with an energy of 500 mJ produced greater retentions and improved adhesive strength.

Currently, there are few studies on the use of the

Er:YAG laser in the surface treatment of lithium disilicate or other types of ceramics, thereby limiting comparison with our results. However, a laser with a power of 8 watts, energy of 400 mJ, frequency of 20 Hz, and pulse of 50 µs could be a viable alternative. One of the limitations of this in vitro research is its inability to replicate oral conditions. However, it helps dentists understand the behavior of dental materials, resulting in predictable and long-lasting treatments. Furthermore, we suggest continuing the research using the same Er:YAG laser but with different materials, such as printed resin, zirconium, and lithium disilicate. The discs were not thermocycled, so future research simulating oral conditions is needed.

Conclusion

Surface treatment performed with a 2940 nm ER:YAG laser showed that the SBS of Group 1 at a laser energy of 300 mJ/50 µs was similar to that of the Control group, which corresponds to the conventional treatment with 10% hydrofluoric acid. However, the surface treatment that produced the highest strength was group 2, with a laser energy of 400 mJ/50 µs. In contrast, the group that obtained the lowest strength was group 3, with a laser energy of 500 mJ/50 µs, generating highly expulsive zones in lithium disilicate. Finally, the use of a 2940 nm ER:YAG laser with an energy of 400 mJ/50 µs is recommended as a clinical alternative for performing surface treatments on lithium disilicate restorations, avoiding the use of agents such as acids that can cause burns to the skin, eyes and other adjacent tissues of the patient and operator.

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Authors' Contribution

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Writing–review & editing: Cesar Manuel Poquioma Choque, Rodolfo Calle-Chavez, Fabricio Hinojosa Pedraza, Katherine Joselyn Atoche-Socola.

Competing Interests

The authors declare no conflicts of interest.

Ethical Approval

The present *in vitro* study followed the standards required by the Ethics Committee of the Universidad Científica Del Sur. (registration: POS-53-2023-00630).

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