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Evaluation of the effect of etching with ytterbium fiber laser on the bond strength, color stability, and fracture analysis of lithium disilicate ceramics to bovine teeth: an in vitro study

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Abstract

Purpose This study aimed to investigate the impact of 1070 nm Ytterbium Fiber Laser (YFL) on the shear bond strength of lithium disilicate ceramics to enamel.

Methods Fifty-four freshly extracted bovine teeth were embedded in acrylic resin, with labial surfaces exposed. The teeth underwent etching with phosphoric acid, followed by the application of bond resin. Ceramic samples of 0.5 mm, 1 mm, and 1.5 mm thickness were obtained from lithium disilicate CAD blocks using a precision cutting tool. Samples were divided into two subgroups according to surface treatment method: one group was treated with 4.5% hydrofluoric acid for 20 s, while the other was treated with a 20 W average power YFL. One sample from each subgroup underwent SEM analysis; the remaining samples were cemented to prepared bovine teeth using composite resin cement. Color measurements were performed before and after surface treatments. Shear bond strength was evaluated using a universal testing machine with a crosshead speed of 0.5 mm/min. Fracture analyses were conducted using a stereomicroscope. Statistical analyses were performed using two-way ANOVA and two-way ANOSIM.

Results According to the two-way ANOVA results, the ΔE_{00} values were significantly higher in all thickness groups treated with YFL than in those subjected to acid treatment. Two-way ANOSIM revealed that neither sample thickness nor surface treatment had a statistically significant effect on shear bond strength. SEM analysis revealed micro-roughness in the acid-treated samples and mini-laser spots in the laser-treated groups, and no microfractures or cracks detected in any of the groups.

Conclusion The shear bond strengths of lithium disilicate ceramics, whether treated with YFL or hydrofluoric acid, were found to be comparable. These findings suggest the potential utility of 1070 nm YFL for ceramic etching, supporting the need for further investigation in dental applications.

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Keywords 1070 nm Ytterbium Fiber Laser, Lithium disilicate, SEM

Introduction

CAD/CAM technology, increasingly favored in dentistry, expedites the production of high-quality, aesthetically pleasing indirect restorations, meeting the rising demand for tooth-colored materials with superior mechanical properties and aesthetics [1]. Lithium disilicate glass-ceramic blocks are widely preferred in aesthetic dentistry due to their superior optical and mechanical properties, as long as their long-term survival rates [2]. The optical characteristics of CAD/CAM dental ceramics are essential for achieving satisfactory aesthetic restorations in the anterior region [3].

The cementation of glass ceramics with resin cement enhancesadhesion durability, which is crucial for the long-term stability of restorations. A loss of adhesion between the substrates can significantly reduce the load-bearing capacity of crowns under fatigue [4]. The stronger bond between the ceramic and resin cement increases fracture resistance [5] and marginal adaptation [6] and reduces microleakage [7] which enhances the retention of the restoration [8, 9].

The application of ceramic surface treatments aims to improve the adhesion of the hydrophobic bonding cement by increasing the micro-roughness [10].

The standard method for roughening glass ceramic restorations is etching with hydrofluoric acid [11]. Hydrofluoric acid etching selectively removes the glassy matrix of the ceramic and exposes crystalline structures [12]. Thus, the surface energy of the ceramic surface increases, which strengthens the chemical bond between the inorganic matrix of the ceramic and the organic matrix of the resin cement and also increases the micromechanical retention with the resin cement [13, 14]. Regarding the mechanical behaviour after etching with hydrofluoric acid, high concentrations of hydrofluoric acid and extended application times reduce the flexural strength of ceramics [15]. Improper use of hydrofluoric acid can produce micro-defects, grooves, and cracks on the surface of the lithium disilicate ceramic, which can weaken the strength of the lithium disilicate ceramic [16–18].

Hydrofluoric acid is caustic, considered dangerous for both dentists and patients and therefore cannot be used intraorally [19]. It also reduces bond strength when used in high concentration, as well as limiting ceramic repair [20]. Hydrofluoric acid poses a potential health hazard to dentists due to its toxicity; hydrofluoric acid can damage the skin or irritate the eyes if accidentally contacted, or damage dentists' lungs in the long term due to its volatility [19–22].

Lasers have been used as an alternative to traditional methods in ceramic surface treatment in the last decade. In the literature, CO_2 lasers [23, 24], ND: YAG lasers [25–29], ER: YAG lasers [23, 28–31], and Er, Cr: YSGG lasers [20, 31] have been used for roughening ceramic surfaces. After the first introduction of the Ruby laser (Ruby laser) by Maiman in 1960, other laser types such as CO_2 and ND: YAG lasers were produced and started to be used in dentistry [27, 28]. However, Erbium lasers have become more popular in dentistry due to the increased melting, cracks, fractures, carbonization, and pulp temperatures of CO_2 and ND: YAG lasers on hard tissues and dental ceramics [32].

Pulsed ytterbium fiber lasers (YFL) operating at 1070 nm, which emit pulses with a peak power of over 80 W and a duration of microseconds, can be applied in various fields such as gynaecology, abdominal surgery, cardiovascular surgery, and dental treatment [33].

Previous studies have shown that YFL is more advantageous than other laser types for roughening zirconia. The fact that the YFL can reach a smaller focal diameter compared to other laser types has been revealed as the greatest advantage of these lasers [33–35]. The use of YFL for roughening zirconia in previous studies has been considered remarkable and is in the process of being developed with current studies [33–35].

To the best of the authors' knowledge, there is only one study from the indexed literature on the use of YFL in surface roughening of lithium disilicate ceramics. In this study, the surface of lithium disilicate ceramics was roughened with 1070 nm YFL, and the surface morphology of the samples was examined by scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS) analysis [36]. However, in this study, the effect of roughening with YFL on the adhesion was not investigated. Therefore, this pilot study aims to investigate the effect of YFL on the shear bond strength of lithium disilicate ceramics. The first null hypothesis posits that there is no statistically significant variance in the bond strengths of lithium disilicate ceramics of varying thicknesses when subjected to treatment with either YFL or hydrofluoric acid and the second null hypothesis is no significant difference regarding color stability among the tested materials.

Materials and methods

Sample size calculations were performed using the means and standard deviations from a similar previous study [33] which were incorporated into the power calculation formula with an 80% power level (Minitab 18, Minitab LLC, USA). Based on these calculations, it was determined that 9 samples per group would be required, resulting in a total of 54 samples. Additionally, six more samples were prepared for SEM analysis. Therefore, a total of 54 freshly extracted permanent mandibular incisor bovine teeth were used in this study. The animal teeth used in this study were obtained from commercially slaughtered animals. These animals were not owned by any institution, individual, or farm, and therefore, informed consent from owners was not applicable. The collection of animal teeth adhered to ethical considerations and regulations for the use of animal by-products in research. The criteria for inclusion were as follows: teeth in good health without cavities or fractures, and no history of exposure to chemical substances such as hydrogen peroxide, alcohol, or formaldehyde. The crowns of the teeth were cut from the roots, soft tissue debris was removed, and the labial surface of the crown was placed in the center of the square mold and the specimens were embedded in auto-polymerized acrylic resin. The teeth, embedded in acrylic resin, were preserved in a 0.1% thymol solution and kept refrigerated at 4 °C. To obtain a similar enamel surface, the labial surfaces of the teeth were ground with 180, 320, 600, and 1200 grit silicon carbide paper. The surface of the teeth was etched with 35% phosphoric acid (K-Etchant, Kuraray Noritake, Tokyo, Japan), and a resin bond (Panavia V5 Tooth Primer, Kuraray Noritake, Tokyo, Japan) was applied.

A total of 60 lithium disilicate (LDS) samples were obtained by sectioning ceramic blocks (E-max CAD, Ivoclar Vivadent AG, Schaan, Liechtenstein) into thicknesses of 0.5 mm, 1 mm, and 1.5 mm ($n = 20$ each) and shaping them into 5 × 5 mm squares using a precision cutting tool (Struers Minitom; Struers, Copenhagen, Denmark). To reach their ultimate strength and esthetic qualities, pre-crystallized samples were transferred to a ceramic furnace (Programat, EP 510, Ivoclar Vivadent AG, Schaan, Liechtenstein) for the crystallization process. The LDS specimens underwent a pre-drying phase at 403°C for 6 min, followed by a gradual temperature increase at a rate of 50°C/min until reaching 850°C. This temperature was maintained for 9 min to ensure complete crystallization of the LDS. Subsequently, the samples were allowed to cool to room temperature. With the application of a fine layer of glazing material with a smooth brush, the samples were fired on a furnace tray following the manufacturer's instructions.

Prior to applying any surface treatments to the samples ($n = 60$), the initial color values L*, a*, and b* were recorded using a spectrophotometer (Vita Easyshade®, Vita Zahnfabrik, Bad Säckingen, Germany). Following the device calibration according to the manufacturer's instructions, measurements were conducted by a single researcher. These assessments were carried out on a white background (L*, a*, b*), at a specific time of day under daylight conditions. To block external light from affecting the samples, a silicone model compatible with the spectrophotometer was designed and placed around the samples. The silicone model was positioned on a flat surface, and measurements were taken by placing the spectrophotometer directly onto the model and aligning it vertically. For each sample, three L*, a*, and b* values were measured across the entire surface, and the average of these measurements was taken as the initial value.

These samples were then divided into two groups, with each group containing samples from all three thicknesses. Samples in the first group, consisting of ($n = 10$) samples, were subjected to etching with hydrofluoric acid (4.5% IPS Ceramic Etching-Gel; Ivoclar Vivadent, Schaan, Liechtenstein) for a duration of 20 s. Following etching, the samples were rinsed under running water and cleaned in a digital ultrasonic cleaner for 180 s before being air-dried.

In the present study, a design composed of both straight and diagonal lines (distance between lines of 0.05 mm), was employed. This design was generated using software tailored for graphic design and vector-based illustrations (CorelDRAW, Corel Corporation, Ottawa, Canada). A 1070 nm ytterbium-doped pulsed fiber laser (FLM 1530 ATT, Robart Laser, İstanbul, Turkiye) with a maximum average output power of 20 W [37], a fixed pulse duration of 100 ns, and a repetition rate of 20 kHz was the laser source with air cooling used to etch the other samples. The lens used with the laser device had a focal length of 160 mm, utilizing a laser beam spot size of 80 µm [35]. The laser beam was directed over the LDS surface in a noncontact mode at a working distance of 17.8 mm with laser focusing on the LDS via horizontal and diagonal scanning with the air-cooling system in the laser device.

Subsequently, color measurements of the samples with treated surfaces were repeated under the same conditions as the initial measurements, and the color change (ΔE_{00}) values were determined.

In this study, following the guidelines set by Paravina et al. [38], the clinically perceptible and acceptable thresholds for color change were established at $\Delta E_{00} = 0.8$ and 1.8, respectively. Color stability (ΔE_{00}) was calculated using the CIEDE2000 formula [39].

$$\Delta E_{00} = \sqrt[2]{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$$

Using this formula, the CIELAB values were transformed into the CIEDE2000 parameters L′ (lightness), C′ (chroma), and h′ (hue). Within the CIEDE2000 uniform color space, ΔL′, ΔC′, and ΔH′ were calculated as the metric differences between the corresponding values of the samples. To adjust (weight) the metric differences for each coordinate in the CIEDE2000 system, three empirical terms were applied: $K_L S_L$, $K_C S_C$, and $K_H S_H$. R_T refers to the rotation function, which represents the interaction between chroma and hue differences, particularly in the blue region. The parametric factors of the CIEDE2000 color difference formula were specified as follows in this study.

One sample from all groups was separated randomly to be examined by SEM (Carl Zeiss, Sigma 300 VP, Jena, Germany) after surface treatment.

After etching procedures, ceramic primer (Clearfil Ceramic Primer, Kuraray Noritake, Tokyo, Japan) was applied to all specimens. LDS specimens were bonded with composite resin cement (Panavia V5, Kuraray Noritake, Tokyo, Japan). A universal test machine (Instron 3345; Instron Norwood, MA, USA) (0.5 mm/min) was used to measure the shear bond strength of the ceramic specimens with bovine teeth. A steel rod featuring a chisel-shaped extremity was affixed to the crosshead to administer onto LDS specimens, inducing a shear force at the junction of the ceramic tooth interface (Fig. 1). The crosshead was moved downward at a speed of 0.5 mm/min, and the LDS samples were loaded until fracture. The debonding force required for debonding was documented in Newton (N) and computed in MPa by correlating the Newton force with the surface area of the LDS sample (sample surface area was 25 mm^2).

Fig. 1 A photographic illustration of the shear bond strength test being conducted using an Instron machine

Table 1 Two-way ANOVA results of color change of the groups

	Thickness			Test statistics†	
	0.5	1	1.5		
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	*F*	*p*
Treatment					
Acid	$1.27 \pm 0.46^{A, x}$	$0.51 \pm 0.37^{A, y}$	$1.12 \pm 1.02^{A, xy}$	3.720	**0.031**
Fiber	$1.92 \pm 0.81^{B, x}$	$1.40 \pm 0.68^{B, xy}$	$2.45 \pm 0.32^{B, xz}$	6.370	**0.003**
Test Statistics‡					
F	4.851	9.046	20.216		
P	**0.032**	**0.004**	**0.000**		
Thickness effect: *F = 8.736* ***p = 0.001*** **Treatment Effect**: *F = 31.405* ***p = 0.000***					
Thickness x Treatment Effect: *F = 1.354 p = 0.267*					

SD: Standart deviations, †: Intragroup comparison between thicknesses, Superscripts x and y indicate differences in thickness, ‡:comparison between treatments, Superscripts A and B indicate differences in treatment measurements. Groups with the same superscripts are statistically similar

Table 2 Descriptive statistics of shear bond strength (MPa)

Thickness	Surface Treatments									
	YFL					Acid				
	Mean	**SD**	**Median**	**Min**	**Max**	**Mean**	**SD**	**Median**	**Min**	**Max**
0.5 mm	3.98	2.25	3.92	0.91	8.13	2.94	1.29	2.99	0.43	0.99
1 mm	3.31	1.64	3.72	0.52	4.92	3.47	2.18	3.63	0.97	6.33
1.5 mm	2.71	1.61	3.20	0.50	4.74	3.76	1.21	3.98	1.76	5.72

Sd: Standard deviation, min: minimum, max: maximum

A stereomicroscope (BX 60, Olympus, Tokyo, Japan) was used for fracture-type analyses. Fracture type analysis was performed as type 1: cohesive failure, type 2: adhesive failure in which more than 50% of the resin cement was observed on the ceramic surface and adhesive failure in which less than 50% of the resin cement was observed on the ceramic surface, type 3: mixed failure fracture type in which both adhesive and cohesive failure were observed together [29].

Statistical analysis

The data were evaluated in the statistical package program (SPSS 22.0 for Windows; IBM Corp, SPSS Inc, Chicago, IL, USA). The normality of the samples was evaluated by Shapiro-Wilk analysis and the homogeneity of group variances was evaluated by Levene's test. The ΔE_{00} values conform to a normal distribution, whereas the SBS values deviate from it. Subsequently, the obtained ΔE_{00} data, comprising lithium disilicate samples with varying thicknesses and surface treatments, were subjected to two-way analysis of variance (ANOVA) ($\alpha = 0.05$) followed by Bonferroni test. The SBS data were analyzed using two-way ANOSIM ($\alpha = 0.05$).

Results

Table 1 presents the mean and standard deviation of ΔE values for all thicknesses and surface treatments, along with the results of the two-way ANOVA and Bonferroni tests. Two-way ANOVA analysis of colour stability results demonstrated that there was a significant difference between surface treatments and thickness groups. No significant difference was found between thickness and surface treatment interaction. The ΔE_{00} values observed in all thickness groups following YFL treatment were significantly greater than those recorded for the acid-treated groups.

Within the acid-treated group, the 0.5 thickness group showed a significant difference when compared to the 1 and 1.5 groups. In the YFL-treated group, a significant difference was observed between the 1 and 1.5 thickness groups.

The two-way ANOSIM results demonstrated that the shear bond strengths of the LDS samples were similar regardless of their thickness ($p = 0.291$, $R = 0.016347$) or type of surface treatment ($p = 0.266$, $R = 0.021262$). The descriptive statistics of SBS values were shown in Table 2.

Table 3 shows the results of the fracture type analysis. The most notable data in this table is that all specimens in the acid-etched groups showed the adhesive failure type in which more than 50% of the resin cement was observed on the ceramic surface (type 2). In the laser roughening groups, adhesive failure type with less than 50% of the resin cement on the ceramic surface (type 2) was mostly observed. A laser-etched 0.5 mm thick ceramic sample was fractured. No mix failure type was observed in any sample.

The 3 K magnification results obtained in SEM analysis are shown in the Fig. 2. While micro-roughness is observed in acidic samples, mini-laser spots are observed in laser groups. No microfractures and cracks were observed in all groups.

Table 3 Fracture-type analysis results that obtained by examining ceramic surfaces with a stereomicroscope

	Cohesive Failure	Adhesive Failure (more than 50% of the resin cement on the ceramic surface)	Adhesive Failure (less than 50% of the resin cement on the ceramic surface)	Mixed Failure (adhesive and cohesive failure)
YFL 0.5 mm	1 11.11%	2 22.22%	6 66.66%	0 0%
YFL 1 mm	0 0%	3 33.33%	6 66.66%	0 0%
YFL 1.5 mm	0 0%	4 44.44%	5 55.55%	0 0%
Acid 0.5 mm	0 0%	9 100%	0 0%	0 0%
Acid 1 mm	0 0%	9 100%	0 0%	0 0%
Acid 1.5 mm	0 0%	9 100%	0 0%	0 0%

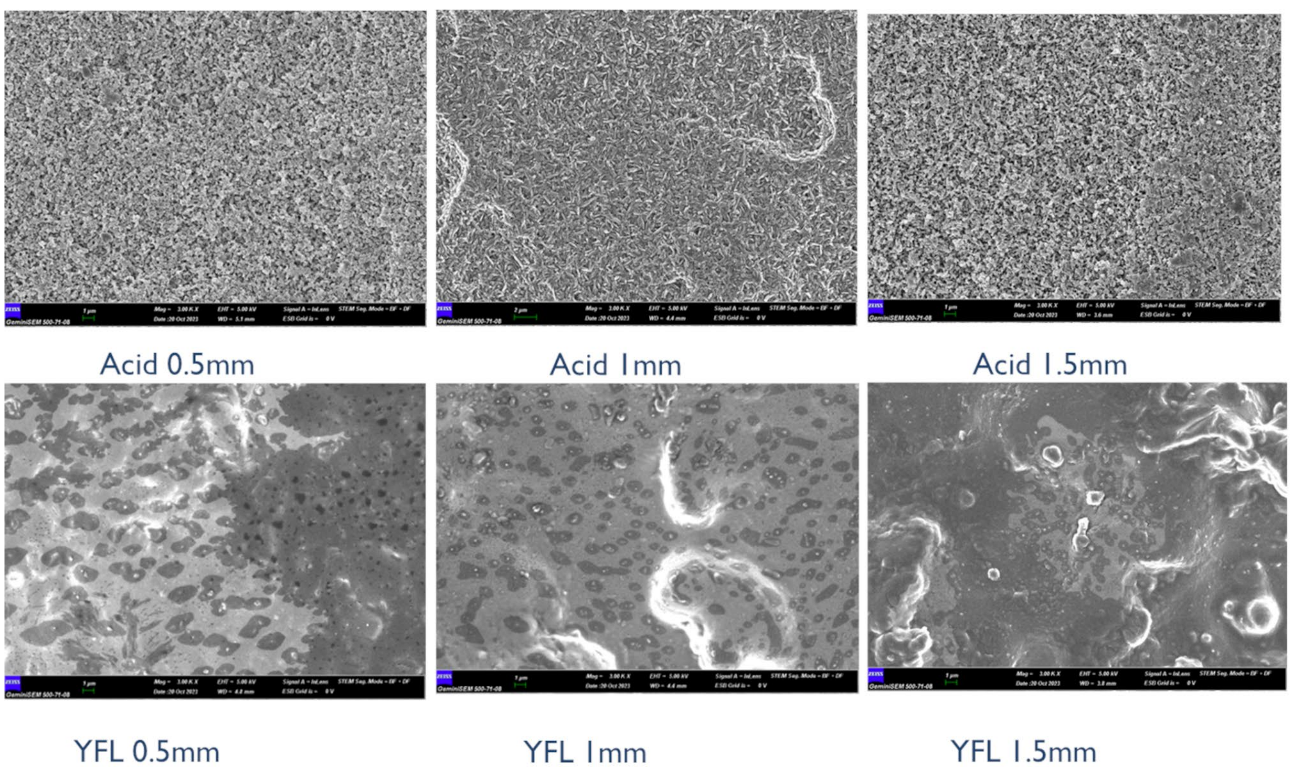

Fig. 2 SEM analysis of study groups

Discussion

The first null hypothesis of this study, stating that 'there is no significant difference between the bond strengths of lithium disilicate ceramics of different thicknesses treated with YFL and hydrofluoric acid,' failed to be rejected, and the second null hypothesis was rejected related to color differences.

Bovine teeth have emerged as a viable substitute for human teeth in laboratory research for several reasons. Their ready availability, lack of carious lesions, and manageable size make them a convenient choice for various technical procedures [40] De Carvalho et al. [41], in their systematic review and meta-analysis, concluded that bovine teeth could effectively serve as alternatives to both permanent and deciduous human teeth for evaluating shear bond strength, encompassing both enamel and dentin substrates. So, in this study, bovine teeth were selected due to their easy accessibility and freshness.

The importance of surface treatment in improving the bond between resin cement and restorative materials has been emphasized in the literature [42]. The primary purpose of surface treatment is to promote micro-roughness and therefore increase the surface area. Subsequent application of the ceramic primer facilitates adhesion to the hydrophobic luting cement, providing both micromechanical interlocking and chemical bonding [43, 44].

Airborne particle abrasion with Al_2O_3, silicate coating, hydrofluoric acid etching, and combinations of these techniques are surface treatment techniques used for surface roughening. Airborne particle etching utilizing Al_2O_3 particles is a surface treatment commonly employed for ceramics. It has demonstrated practicality and effectiveness, particularly in generating an active and textured surface on aluminium oxide ceramics [45, 46]. Menees et al. [47] reported that alumina particle corrosion at high pressures significantly reduces flexural strength by creating stress risers in LDS and stated that it should not be used. They stated that it is appropriate to use hydrofluoric acid etching to increase micromechanical retention and clean the engraving surface of the restoration before bonding. The glassy ceramic matrix is selectively removed by hydrofluoric acid etching, revealing the crystalline structures (12). As a result, the surface energy of the ceramic rises, strengthening the chemical link between the inorganic ceramic matrix and the organic resin cement matrix as well as the ceramic's micromechanical retention with the resin cement [13, 14]. Therefore, HF etching was used to compare the effectiveness of YFL in this study. Moreira et al. reported that hydrofluoric acid etching at concentrations exceeding 5% had an adverse effect on flexural strength [48]. Consequently, hydrofluoric acid at a concentration of 4.5% was employed in the study.

In recent times, laser irradiation has emerged as an alternative technique for creating surface roughness on ceramics, aiming to enhance the adhesion of composite resin. In the literature, etching processes with various laser types have been evaluated to increase the bonding strength of lithium disilicate ceramics. Hou et al. [30] applied Er: YAG laser surface treatment to different CAD/CAM ceramics using different power parameters and showed that Er: YAG laser roughening significantly increased the shear bond strength. Ahrari et al. [24] applied CO_2 laser, hydrofluoric acid, and their combination to lithium disilicate ceramics and reported that the most effective method was the combined method. Kursoğlu et al. [20] applied ErCr: YSGG laser at different powers to lithium disilicate ceramics and the bond strength increased significantly in the groups roughened with laser. Feitosa et al. [29] compared ceramics roughened with Er: YAG and Nd: YAG lasers and reported that Er: YAG laser showed better results. As a result of all these studies, lasers are thought to be effective in the roughening of lithium disilicates and the data obtained in this study agree with these studies. YFL was found to be as effective as hydrofluoric acid in roughening lithium disilicate in increasing the shear bond strength of lithium disilicate.

Fiber lasers are extensively utilized in the industrial sector, particularly for tasks like material processing, such as cutting and marking. In dentistry, the application of YFL is primarily notable for its role in the surface processing of zirconia ceramics. Firstly, Mutluay Ünal et al. [33] compared the bond strength of sandblasted and silica-coated ceramic discs with YFL and found the highest bond strength in the fiber laser-treated groups. On the contrary, Fornaini et al. [35] showed higher bonding results in resin cement adhesion in zirconia specimens roughened with YFL; but did not show a significant difference with the untreated specimens. In parallel with Mutluay Ünal et al. [33], Toyoda et al. [34] showed that surface roughness and bond strength increased significantly in YFL-treated specimens. Roughening with YFL is still controversial for zirconia ceramics and roughening studies with YFL are very limited in the literature.

Fornaini et al. [36] roughened the surfaces of lithium disilicate ceramics using a 1070 nm pulsed fiber laser applied at different powers and examined the ceramic surfaces with a stereomicroscope, SEM, and EDS analysis. They also evaluated the temperature changes in ceramics. As a result of their studies, they concluded that YFL may contribute to the adhesion of lithium disilicate. Their research led them to the conclusion that YFL could be useful in lithium disilicate adhesion when optimum parameters are considered. This study's findings corroborate those of Fornaini et al. [36]. Although the SEM results demonstrated superior performance in the acid etching group compared to the YFL-treated group, which suggests that acid etching may be the more effective technique, this study also revealed that etching with YFL achieved adhesion results on teeth comparable to those obtained with hydrofluoric acid etching.

It's apparent that as the thickness of ceramic samples increases, the transmitted laser power decreases. Therefore, for this study, samples ranging from 0.5 to 1.5 millimeters in thickness were prepared to mimic restorations of varying thicknesses. The investigation focused on examining the durability and presence of microcracks in ceramic samples of different thicknesses when exposed to laser through SEM analysis. Despite the absence of observed microcracks and fractures in the analyzed samples, the occurrence of cohesive fracture in a 0.5 mm thick sample in the fracture type analysis suggests that this power parameter might be excessive when applied to very thin restorations.

In this study, the thresholds for clinical perceptibility and acceptability were established as $\Delta E00 = 0.8$ and 1.8, respectively, based on criteria reported in the literature [38, 49]. Laser treatment resulted in greater color changes compared to acid treatment. Specifically, in the laser-treated groups, the color change exceeded the acceptable threshold for specimens with thicknesses of 0.5 mm and 1.5 mm. Conversely, in the acid-treated groups, the color change surpassed the perceptibility threshold for specimens with the same thicknesses. These discrepancies may be attributed to the differential effects of varying laser energy levels on ceramics of different thicknesses [50].

As a suggestion based on the findings of this study, YFL may be developed as a potential alternative to hydrofluoric acid for surface roughening of lithium disilicate ceramics. This development could involve testing and establishing various laser setting parameters, alongside further examination of the resulting bonds through artificial aging and functional protocols to evaluate their durability and efficacy. Further researches are warranted to validate the effectiveness and safety of YFL for ceramic etching.

Limitations.

This study was planned under in vitro conditions. It should be taken into consideration that it does not directly reflect the clinical situation. Additionally, this study did not compare various laser parameters, acid concentrations, and application times. In this study, the parameter used for zirconia in the literature was used. It is not known with which parameters the bond resistance of lithium disilicates will give better results. Another limitation of this study is that the samples were not subjected to aging. In future studies, tests with different laser parameters should be carried out, the effect of aging on the bonding strength of the samples should be investigated and the results should be evaluated with in vivo clinical experiments.

Conclusions

Within the results of this study,

1. The shear bond strength of lithium disilicate ceramics surface roughened with YFL and hydrofluoric acid was found to be similar.
2. These results indicate that laser treatment leads to more pronounced color changes compared to acid treatment, particularly as the ceramic thickness increases, and that laser energy has varying effects on ceramics of different thicknesses. Therefore, as a suggestion, YFL application should be considered primarily for posterior teeth, where aesthetic considerations are of lesser importance compared to the anterior region.
3. The fracture-type and SEM analyses revealed that the acid-etched groups showed more resin cement remaining on the ceramic surface, while the laser-treated groups had less, with no microfractures or cracks observed in any of the groups, highlighting the effectiveness of the treatments in maintaining the integrity of the specimens.

Abbreviations

CAD/CAM Computer-Aided Design/Computer-Aided Manufacturing
CO_2 Carbon Dioxide
Nd:YAG Neodymium-Doped Yttrium Aluminum Garnet
Er:YAG YAG: Erbium-Doped Yttrium Aluminum Garnet
Er, Cr:YSGG Erbium, Chromium-Doped Yttrium Scandium Gallium Garnet
YFL Ytterbium Fiber Laser
SEM Scanning Electron Microscope
EDS Energy Dispersive Spectroscopy
LDS Lithium Disilicate
SBS Shear Bond Strength
Al_2O_3 Aluminum Oxide
HF Hydrofluoric Acid

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Clinical trial number: not applicable.

Author contributions

This study was conceived and designed by G.A.D. and E.T.Ç., with both authors also responsible for the acquisition, analysis, and interpretation of data. Both authors have approved the submitted version and take personal accountability for their contributions. They further commit to addressing any questions regarding the accuracy or integrity of the work, even for aspects beyond their direct involvement, by ensuring thorough investigation, resolution, and proper documentation in the literature.

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Data availability

All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

This study complied with all relevant institutional, national, and international ethical guidelines for the use of animals in research, including those outlined in the Basel Declaration. The animal teeth used in this study were obtained from commercially slaughtered animals that were not owned by any institution, individual, or farm; therefore, informed consent was not applicable. Since the study involved the use of animal by-products rather than direct experimentation on live animals, it was conducted in accordance with ethical regulations. Ethical approval was granted by the Aydın Adnan Menderes University Faculty of Dentistry Non-Interventional Clinical Research Ethics Committee (Protocol No: 2024/10, Decision No: 06). The study adhered to all ethical principles and regulatory requirements governing the use of animal-derived materials in research.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Clinical trial number

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