IJL, Issue 2, Vol. 22, 2023
https://doi.org/10.31900/ijl.v22i2.408 **Research Article**

IRAQI JOURNAL OF LASER

Evaluation of Lithium Disilicate Surface Morphology Treated with Er,Cr:YSGG and Fractional CO_2 Laser

Noor Azad Mohammed[1,*], Zainab F. Al-Bawi[1], Balsam Saadi Abdulhameed[2]

[1]*Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq*
[2]*Al-Imamen Al-Kadmen Medical City, Ministry of Health, Baghdad, Iraq*
* *Email address of the Corresponding Author: Nour.Azad1202a@ilps.uobaghdad.edu.iq.*

Article history: Received 24 July 2023;Revised 20 Aug 2023; Accepted 11 Sept 2023; Published online 15 Dec2023

Abstract: The use of indirect, all-ceramic restorations has grown in popularity among dentists. Studies have demonstrated that for indirect ceramic restorations to be effective over time, cement and ceramic must be bonded in a stable manner. Chemical, mechanical, and laser irradiation are among the methods used to precondition ceramic surfaces in order to increase bond strength.
The objective of the study: This study was performed to investigate the roughness values and surface topography of lithium disilicate glass-ceramic treated with conventional methods and different Er,Cr:YSGG, and fractional CO_2 laser conditioning parameters.
Material and methods: Sixty samples of lithium disilicate glass-ceramic were divided as follows: 1- (n = 10) untreated; 2- (n = 10) Hydrofluoric acid etched; 3- (n = 10) conditioned by Er,Cr: YSGG laser at (7 W, 25 Hz, 50/50% Water/Air, pulse duration 60 us, irradiation time 2 min); 4- (n = 10) conditioned by Er,Cr:YSGG laser at (5 W, 25 Hz, 50/50% Water/Air, pulse duration 60 us, irradiation time 2 min); 5- (n = 10) conditioned by fractional CO_2 laser at (power 8 W, pulse duration 10 ms); 6- (n = 10) conditioned by fractional CO_2 laser at (power 6 W, pulse duration 10 ms). Then evaluated by: Profilometer, and scanning electron microscopy.
Results: The highest roughness values were found in CO_2 laser power 8 W treated samples, followed by Er,Cr:YSGG laser power 7W treated samples. The hydrofluoric acid-etched samples showed roughness values comparable to those of CO_2 laser-irradiated samples with a power of 6 W. The untreated sample showed the smoothest surface with the lowest roughness value.
Conclusion: The application of Er,Cr:YSGG, fractional CO_2 lasers enhances the surface roughness of lithium disilicate samples positively, showing the promised results of using these parameters in bonding procedures.

Keywords: laser, surface treatment, ceramics.

1. Introduction

In order to restore the enamel, dentin, structural support, protection, and physical integrity, current glass ceramic fixed dental prostheses take advantage of and benefit from combining the features of crystalline ceramics with those of glasses. They help to bridge the gap between synthetic and realistic aesthetics while performing an essential function in oral rehabilitation. Contrary to restorations made of metal, polymer-based (Lien et al., 2015). All ceramic restorations have been developed in response to the rising need for aesthetics in restorative dentistry due to their superior esthetic metal-free properties.

Many modern dental indirect restorations are made of lithium disilicate (LD) glass ceramics. Using the hot press method, lithium disilicate ceramics have a better potential for restoration thanks to their translucent and aesthetically pleasing properties than zirconia.

In comparison to leucite-reinforced glass ceramics, the flexural strength of lithium silicate ceramics is significantly higher with better mechanical strength, including fracture toughness, chemical endurance, and abrasion resistance (Alkhudhairy et al., 2020). These properties are provided to ceramics by the crystals in lithium disilicate. However, ceramics' poor physical and bonding qualities continue to be an issue. With such widespread application, it is crucial that dental ceramic and resin composites bond securely and reliably; both micromechanical attachment and chemical bonding via a silane coupling agent are common ways of forming this connection. In order for indirect ceramic-bonded restoration or direct ceramic repair to last and look good in the mouth, etching the ceramic surface properly is a must. The surface energy of ceramics and their bonding potential to resin are both altered by acid etching, which also enhances their wettability (Colares et al., 2013).

There are different surface treatment techniques for ceramic's internal surface to create micro-porosities for increasing the surface area and improving the bonding between the restoration and the dental structure. Lithium disilicate ceramics can undergo a number of different surface treatment processes, including hydrofluoric acid etching, sandblasting, and laser irradiation. Etching using hydrofluoric acid is the gold standard for preparing the intaglio surface of glass ceramics.

Ceramic crystalline structures exposed after being etched using hydrofluoric acid, by dissolving and removing the glassy matrix, hydrofluoric acid etchant reveals the elongated crystals of lithium disilicate ceramic, which in turn generate irregularities, peaks, and valleys on the surface. The nature of the ceramic can be changed if the acid etch concentration and/or etching time are increased above what is recommended by the manufacturer. In addition, inappropriate use of the hydrofluoric acid etchant can cause surface micro-defects, grooves, and fissures in lithium disilicate ceramic. Therefore, Lithium disilicate ceramics can be weakened by hydrofluoric acid if the acid is not used correctly per the manufacturer's guidelines (Tarek, 2021).

The capacity of the Er,Cr:YSGG laser to ablate hard dental tissues, as well as its application in different soft tissue treatments, has recently won over trust. The erbium family of lasers has minimal thermal impacts on adjacent tissues because they are well absorbed by hard tissues and water. In addition, it’s a conservative, painless, and noninvasive technique employed for dental work. The use of the Er,Cr:YSGG laser for tooth structure conditioning has also been proven to have antibacterial effects. However, the results of laser treatments might vary depending on a number of factors, such as the length of time spent under the beam, the intensity of the beam, the distance between the surface and the laser, and the type of bonding system used (Vohra et al., 2019).

Micro and macro-irregularities are produced by the Er,Cr:YSGG laser because they rely on the principle of microexplosion during tissue ablation. Additionally, ceramic surface conditioning has been achieved with an Er,Cr:YSGG laser [short pulse duration (60 us)] that results in surface roughness analogous to acid etching. Because HF acid is toxic to patients and cannot be administered intraorally for ceramics, the use of the Er,Cr:YSGG laser is advocated as a more bioacceptable, safe, and straightforward approach to surface modification (Muhammed and Jawad, 2021).

The carbon dioxide laser (CO_2) is frequently utilized intraorally, particularly for soft tissue and hard tissue applications. Because ceramic absorbs nearly the entire wavelength of CO2 laser light, the CO_2 laser is ideally suited for the surface treatment of ceramic materials. CO_2 laser ablation may be an efficient method for conditioning surfaces, thereby improving micromechanical retention and bond strength. The heat initiation of ceramic surfaces by focusing a CO2 laser causes conchoidal fissures, which are the result of surface warming. It is believed that these fractures contribute to the mechanical retention between resin composite and ceramic restorations (Ergun Kunt and Duran, 2018).

The evidence for the role of lasers in the surface conditioning of LD is not yet fully clear. In addition, there is no agreed-upon, standardized procedure for optimizing the laser's power, treatment time, or frequency when it comes to ceramic conditioning. Further, lasers work by surface ablation. (Faris and Al-janabi, 2023). Aiming that the use of Er,Cr:YSGG, and fractional CO_2 laser for surface conditioning of LD ceramics with its modified power, frequency, time, and water/air ratio may show superior or similar results on the surface treatment to the typical usage of HF acid.

2. Material and Method

Sixty IPS E.max 4 mm in diameter and 4 mm in height (4x4x4 mm) cylindrical lithium disilicate glass-ceramic specimens (Ivoclar Vivadent, Schaan, Liechtenstein) were heat-pressed per the manufacturer's instructions. There were no glazing procedures performed on sample surfaces. Underwater chilling, the samples' surfaces were smoothed and polished with silicon carbide paper of 1200 grit by a polishing machine (Laryee Technology Co., Beijing, China). The sample was then placed in an ultrasonic device for 10 minutes to eliminate any impurities or detritus prior to surface conditioning and air drying. At this point, samples were assigned randomly to six groups, each group (n = 10), as follows:

Group 1: In this group (the control group), no surface treatment was applied.

Group 2: The samples' surfaces were etched for 90 seconds with 95% (Pisco Porcelain Etchant, USA) and cleansed with distilled water for 10 seconds to remove any remaining acid, the samples were then air-dried by dental triple syringe.

Group 3: The ceramic surfaces were treated with Er:Cr.YSGG laser irradiation (Millennium, Biolase Technology Inc., San Clemente, CA, USA) using the following laser parameters under air and water spray: Configuration: power = 7 W, wavelength = 2.78 um, 25 Hz W/A 50/50%, pulse duration 60 us, irradiation time (2 min) in sweeping motion. The laser conducting tip was positioned perpendicular to the sample surfaces at a one-millimeter distance fixed by a computer numerical control machine (CNC), using a gold handpiece, 6 MZ um laser tip. The samples were then placed in an ultrasonic device for 5 minutes and 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 and water discharge with the following laser parameters: power setting = 5 W, wavelength = 2.78 um, 25 Hz W/A 50/50%, pulse duration 60 us, irradiation time (2 min) in sweeping motion. The laser conducting tip was positioned perpendicular to the sample surfaces at a one-millimeter distance fixed by a computer numerical control machine (CNC), using a gold handpiece, 6 MZ um laser tip. The samples were then placed in an ultrasonic device for 5 minutes and air-dried.

Group 5: The ceramic surfaces were treated with a fractional CO_2 laser system (CO_2 Fractional Laser, Brochure, JHC1180, China) using the following laser parameters: power = 8 W, wavelength = 10.6 um, pulse duration 10ms, interval 2ms, distance 0.2 mm, two scanning, irradiation area corresponds to the face of the ceramic cylinder with a diameter of 4 mm.
A custom-made Teflon mold was used to hold the ceramic samples and for fixation the articulating arm of the laser device during the scanning process.

Group 6: The ceramic surfaces were treated with a fractional CO_2 laser system (CO_2 Fractional Laser, Brochure, JHC1180, China) using the following laser parameters: power = 6 W, wavelength= 10.6 um, pulse duration 10ms, interval 2ms, distance 0.2 mm, two scannings, irradiation area corresponds to the face of the ceramic cylinder with a diameter of 4 mm.

A custom made teflon mold was used to hold the ceramic samples and for fixation the articulating arm of the laser device during the scanning process.

3. Procedure

A profilometer (surface roughness device) (SRT-6210, China) measured the surface roughness of each specimen before and after the conditioning procedure. For each sample, three readings were obtained, and the average value was calculated and considered. Surface topography evaluation by scanning electron microscopy (SEM) was performed on representative samples from each study group.

4. Statistical analysis

Data analysis and description were performed using Statistical Package for Social Science (SPSS version 26). The values of roughness were statistically evaluated using a one-way ANOVA test, and these values were shown to have a normal distribution by the Shapiro-Wilk test. The P-value was equal to 0.05, regarded as significant.

5. Results

The data on surface roughness for the six study groups that had been collected showed higher statistical significance than the control group. The mean of groups 2, 3, and 6 was (1.220 ± 0.149, 1.233 ± 0.137, 1.131 ± 0.159) respectively with $P < 0.001$, showing comparable results. The highest mean of surface roughness was found in group 5 (CO_2, power 8 W group), and the control group (untreated) had the lowest one as shown in Fig.1. Table (1,2) specifies the results in detail. Figure 2 shows the difference in the scanning electron microscopy (SEM) images of the surface topography between the control group, hydrofluoric acid etched group, and laser irradiated samples.

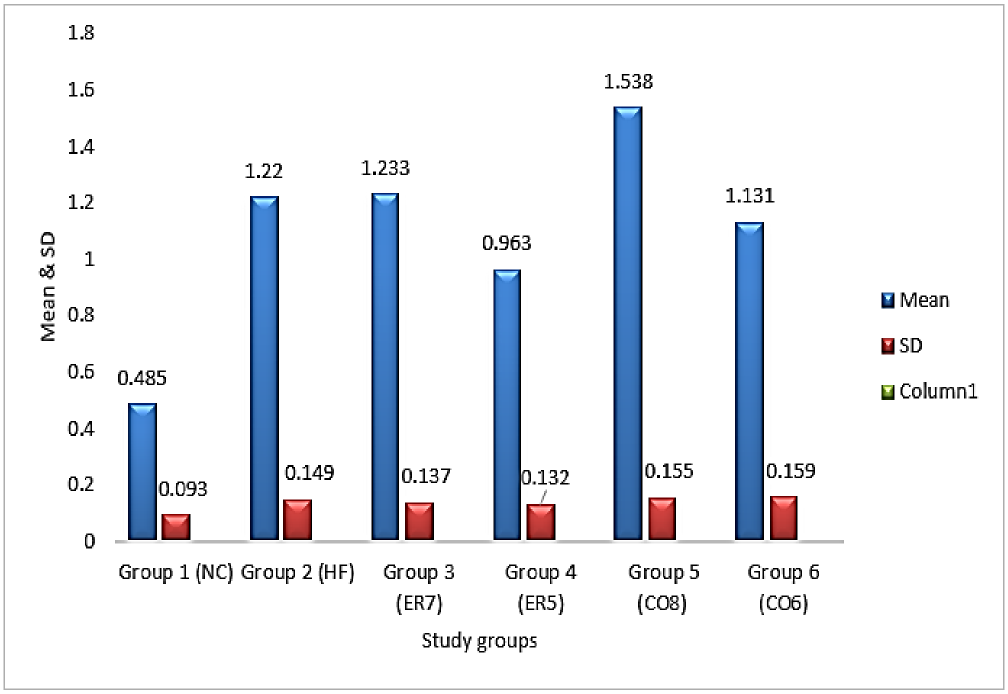

Fig.1: Mean and standard deviation for the surface roughness of the study groups.

Table 1. Descriptive statistics of the roughness values of the study groups.

Study groups	Mean (um)	Standard deviation	Std. error	P-value
Group 1 (NC)	0.485	0.093	0.0625	≤ 0.001 HS
Group 2 (HF)	1.220	0.149		
Group 3 (ER7)	1.233	0.137		
Group 4 (ER5)	0.963	0.132		
Group 5 (CO8)	1.538	0.155		
Group 6 (CO6)	1.131	0.159		

- HS = Highly significant.

Table 2. Descriptive statistics of the roughness values of the study intergroups.

Study groups	Mean difference (um)	Standard deviation respectively	P-value
CN-HF	0.735	0.093 - 0.149	0.000 HS
CN-ER7	0.748	0.093 - 0.137	0.000 HS
CN-ER5	0.477	0.093 - 0.575	0.000 HS
CN-CO8	1.053	0.093 - 0.155	0.000 HS
CN-CO6	0.645	0.093 - 0.159	0.000 HS
HF-ER7	0.013	0.149 - 0.137	0.835 NS
HF-ER5	0.257	0.149 - 0.575	0.000 HS
HF-CO8	0.318	0.149 - 0.155	0.000 HS
HF-CO6	0.089	0.149 - 0.159	0.157 NS
ER7-ER5	0.270	0.137 - 0.575	0.000 HS
ER7-CO8	0.305	0.137 - 0.155	0.000 HS
ER7-CO6	0.102	0.137 - 0.159	0.106 NS
ER5-CO8	0.575	0.132 - 0.155	0.000 HS
ER5-CO6	0.168	0.132 - 0.159	0.01 S
CO8-CO6	0.407	0.155 - 0.159	0.000 HS

- CN = Group 1, HF = Group 2, ER7 = Group 3, ER5 = Group 4, CO8 = Group 5, CO6 = Group 6, HS = Highly significant, S = Significant, NS = Not significant.

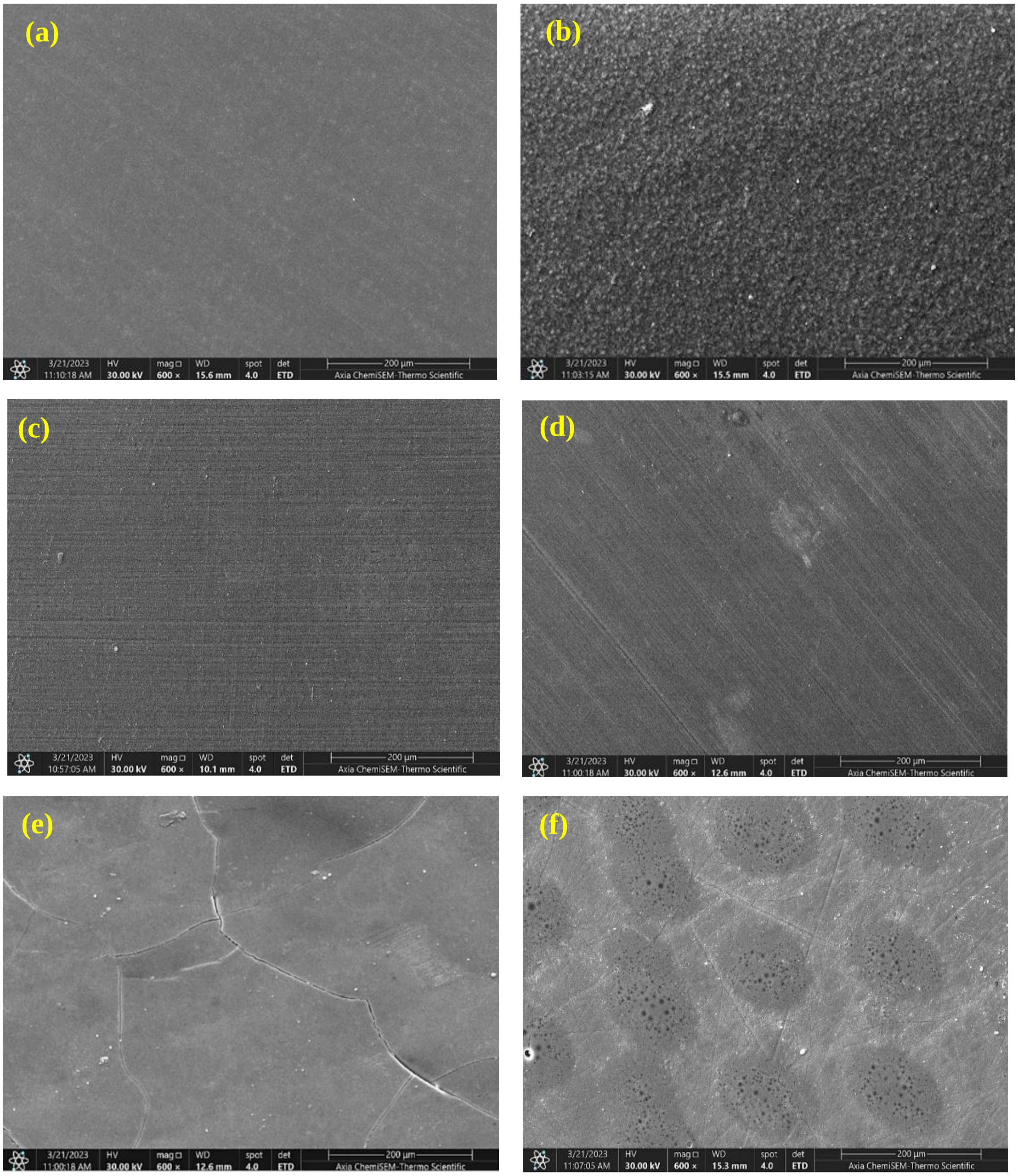

Fig.2: Scanning electron microscopy (SEM) images of the lithium disilicate cylinders at 600X: (A) SEM of untreated sample; (B) SEM of acid etched sample); (c) SEM of laser irradiated (Er,Cr:YSGG) sample, power 7 w; (D) SEM of laser irradiated (Er,Cr:YSGG) sample, power 5 w; (E) SEM of laser irradiated (CO_2) sample power 8 w; (F) SEM of laser irradiated (CO_2) sample power 6 w.

6. Discussion

The assumption was that using laser (Er,Cr:YSGG, fractional CO_2) to condition the surface of lithium disilicate would be superior or equal to using HF.

For optimal adhesion and bonding of ceramics for restorative purposes, inert surfaces must be prepared. There are many ways to accomplish this, including grinding, abrasion with rotary tools (diamond), and abrasion with airborne particles (Al_2O_3), Which provide acceptable bonding despite possible negative effects that cause irreversible changes in the ceramic's surface. Acid etching includes orthophosphoric and hydrofluoric acid, although its usage is constrained by negative effects such as dissolving ceramic's glaze layer, it attacks the glassy phase of ceramics, dissolving the surface to a depth of a few micrometers and as a result, LD crystal protrudes from the glassy matrix (Mohammed and Ali, 2020). It's difficult to apply in the mouth cavity and it has the potential for tissue damage. In addition to these methods, laser irradiation is also used, as are combinations of two or more of these roughening methods (Mirhashemi et al., 2017).

The resulting altered topography increased the surface area for micromechanical bonding. Laser systems have been the subject of substantial research and development due to their ease of use, safety, and increased efficiency. It was shown that the etching precision of Er,Cr:YSGG laser can be affected by the distance of the laser's head from the irradiated surface. To achieve the best results, the optimal distances were determined to be 1 mm for Er,Cr:YSGG (Alhassani and Jawad, 2018). This recommendation was taken into account in this investigation. An earlier study found that using the Er,Cr:YSGG laser at 0.5 W, 10 Hz, pulse duration 230 us ($22.83 \pm 5.07, P < 0.01$) was less effective than using hydrofluoric acid (28.15 ± 4.72 MPa, $P < 0.01$) (Al Rifaiy, 2018). It's interesting to note that extended laser application increases surface roughness, yet the laser generates excessive heat, weakening and overly destroying the surface. Therefore, longer-term laser-treated ceramics showed stronger bond strengths, although somewhat lower than HF (Alkhudhairy et al., 2020). Additionally, there was no discernible difference between the use of the 1.5 W, 10 Hz (27 ± 0.9, $P < 0.001$) and 2.5 W, Hz, time 60 s (21 ± 0.85, $P < 0.001$) on the ceramic materials; both showed noticeably lower mean values than the HF acid-etched treated samples (Mandil et al., 2020). Therefore, higher power was used in this study.

In this study, an examination of the effect of laser surface irradiation on ceramic samples was done by SEM and a profilometer. Also, Er,Cr:YSGG irradiated samples with power 5 W,25 Hz have a uniform smooth surface topography opposite to the acid-etched samples; this disagrees with (Alqerban et al., 2021), who speculated that comparable bond strength treated by Er,Cr:YSGG at 4.5 W, 30 Hz (17.09 ± 1.114, $P > 0.05$) to HF (17.85 ± 1.25, $P>0.05$) is due to the formation of micro-depths and abrasion on the LDC surface.

The Er,Cr:YSGG laser-irradiated samples (power 5 W, 25 Hz) resulted in the lowest Ra value correlating with (Kursoglu et al., 2013), Who hypothesize that the usage of Er:Cr.YSGG laser at 6 W, time 60 s (3.59 ± 1.19, $P > 0.05$) may not be an effective surface treatment technique. Although the use of high power may affect the ceramic surface negatively, the high power (7 W, 25 Hz) Er,Cr:YSGG laser-irradiated samples that used this power for 2 min resulted in increasing surface roughness which correlates with higher bond strength values, correspond with those of (Vohra, Fahim, et al., 2019) using (7 W, 25 Hz, time 2 min.) with a mean and standard deviation of bond strength (19.95 ± 1.014, $P < 0.001$). Repeated applications with low frequency, high power, and longer duration laser parameters are proposed to be more effective in enhancing the roughness and the bonding integrity of ceramic specimens since it is known that laser characteristics can precisely affect the outcome of Er,Cr:YSGG applications. The Er,Cr:YSGG laser ablates tissues using the principle of micro-explosion, resulting in microscopic and macroscopic irregularities (Albaker et al., 2020). In addition, it was found that the mean of surface roughness increased with both the power and duration of the laser treatment. Yet bond strength may decrease at high power due to surface degradation and weakening. Moreover, inadequate micro-depth generation, severe degradation of the matrix phase, or the heat-damaged layer may all contribute to affecting the roughness and the bond strength of laser-prepared ceramic surfaces.

Previous research may have employed inconsistent values for laser power, which may explain the conflicting findings. In contrast to a study by Kursoglu et al., which compared 6 W to 1.5 and 2.5 W, this study increased the power from 5 W to 7 W. In addition, the application period in this study was longer than that of (Kursoglu et al., 2013, Gökçe et al., 2007). The fractional CO_2 laser can increase micromechanical retention and bond strength by roughening the surface via the process of thermomechanical ablation. The use of fractional CO_2 lasers is associated with other benefits, such as the fact that the emission wavelength of the CO_2 laser is almost completely absorbed by ceramics, it is ideally adapted for ceramic surface treatment and scanning the surface by the laser apparatus itself would result in a more homogeneous etching pattern on the ceramic specimen (Ahrari et al., 2017). More research is needed to confirm this assumption.

SEM of the fractional CO_2 groups' surface-treated specimens reveals substance loss and the concentration of hollow depressions at power 6 W, as well as the progressive effect of laser material removal proportional to the parameters and cracks formation at power 8 W. According to SEM analysis, lithium disilicate has a uniform and no cracks on surfaces when irradiated with a 6 W CO_2 laser. This agreed with (El Gamal et al., 2017), who demonstrated that the surface hardness with a CO_2 laser (continuous mode) power 5 W, 60 s was (6.32 ± 0.09, P < 0.0003), Comparing the shear bond strength of irradiated ceramic (16.71 ± 4.04, P = 0.909) to HF acid etched ceramic (16.90 ± 6.42, P = 0.909), revealed no significant differences but confirmed the concept of hydrofluoric acid etching on the surface treatment. It has been reported that whenever focused CO_2 laser beams are used to heat ceramic surfaces, conchoidal tears (typically caused by surface heating) emerge on the surface. The fissures are believed to provide mechanical retention between resin cement and the ceramic surface (Alavi et al., 2021, Zarif Najafi et al., 2014). The fractional CO_2 laser-treated samples at power 8 W have microcracks formation according to the SEM imaging, this may affect the strength of the material in spite of the high surface roughness value and corresponding bond strength. This disagreed with Al Gamal et al., 2017) who reported that 10 W CO_2 laser beams (continuous mode) did not affect microhardness (6.34 ± 0.17, P < 0.0003). Although (AlShahrani et al., 2019) claimed that fractional CO_2 increased the bond strength of ceramics when bonded to a metallic bracket without damaging the surface when using 10 W, 200 Hz, time 60 s,pulse duration 1.75 ms (19.98 ± 2.94, P < 0.05), this was not the case in the present study, as SEM imaging revealed the formation of absolute cracks.

Variations in study outcomes can be attributed to variations in laser parameters, resin cement type, ceramic type, thermocycling procedures, and water storage duration. Blister-like globules and surface cracks on the surface structure of ceramic in laser-irradiated groups lead to increased roughness and greater resin penetration, which may contribute to the micromechanical bond strength in laser-irradiated groups (Hegazy et al., 2016). On ceramic surfaces, the type of laser and the laser's parameters have a significant impact. Since the most important effect of a laser is to convert radiant energy to heat (the thermo-mechanical effect), the most important interaction between the material and laser is the absorption of laser energy by the material's surface (Usumez et al., 2013). To prevent thermal energy from accumulating in surrounding tissue and thereby collateral harm, tissues should be allowed to cool for approximately three times their thermal relaxation time. This can be properly managed (Yeragi et al., 2014).

The in vitro approach used in this study presents certain drawbacks. The outcomes depend on the specific laser used, the parameter, and the ceramic type used in the experiment. The effectiveness of ceramic restorations can also be affected by factors like surface roughness and ceramic strength (which are affected by ceramic heat treatment). For this reason, it is suggested that additional research be conducted utilizing this methodology to examine its effect on the surface roughness and hardness of the ceramic for foreseeable functional results.

7. Conclusions

The application of an Er,Cr:YSSG laser at a power of 7 W enhanced the surface roughness of lithium disilicate samples positively, showing the promised results of using these parameters in bonding procedures of ceramic dental material. The surface treatment by CO_2 laser at 8 W demonstrated roughness values higher than hydrofluoric acid etching with obvious crack formation. The CO_2 laser-irradiated samples at 6 W have comparable Ra values to the HF group.

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تقييم سطح تركيبات الايماكس المعالجة بليزرات الاربيوم كروميوم و ثنائي اوكسيد الكاربون الجزيئي

نور آزاد محمد صالح[1,*] , زينب فاضل الباوي[1] , بلسم سعدي عبد الحميد[2]

[1]معهد الليزر للدراسات العليا, جامعة بغداد, بغداد, العراق
[2]مدينة الامامين الكاظمين الطبية, وزارة الصحة العراقية, بغداد, العراق

*البريد الالكتروني للباحث:Nour.Azad1202a@ilps.uobaghdad.edu.iq

الخلاصة الخلفية و المعلومات : ازداد استخدام تركيبات الاسنان المصنوعة من السيراميك بكثرة في الاونة الاخيرة في طب الاسنان. حيث اظهرت الدراسات وجوب معاملة سطحها بصورة كيميائية او ميكانيكية او بواسطة التشعيع بالليزر من اجل ثباتيتها لاطول فترة ممكنة ونجاحها. **هدف الدراسة**: هذه الدراسة تهدف الى تقييم خشونة وسمات سطح تركيبات الايماكس (سليكات الليثيوم) بعد معالجتها بالطرق التقليدية اضافة الى استخدام الليزر.**المواد والطرق**: ستون عينة من تركيبات الايماكس قسمت الى ستة مجموعات حيث تركت المجموعة الاولى بدون اي معالجة و عولجت المجموعة الثانية بواسطة حمض الهايدروفلوريك اما المجموعة الثالثة والرابعة فعولجت بأستخدام ليزر الاربيوم كروميوم, ثم عولجت المجموعة الخامسة والرابعة بواسطة ليزر ثنائي اوكسيد الكاربون الجزيئي. **النتائج**: اكبر قيمة لخشونة السطح وجدت في المجموعة المستخدم بها ليزر ثنائي اوكسيد الكاربون الجزيئي بقدرة 8 واط و من ثم المجموعة المستخدم بها ليزر الاربيوم كروميوم بقدرة 7 واط. حيث وجد ان مجموعة حمض الهايدروفلوريك وليزر ثنائي اوكسيد الكاربون ذو القدرة 6 واط لديهما ذات القيمة بالنسبة لخشونة السطح. اما المجموعة الاولى الغير معالجة فقد اظهرت اقل قيمة لخشونة السطح. **الاستنتاج**: لقد نتج عن استخدام ليزرات الاربيوم كروميوم و ثنائي اوكسيد الكاربون الجزيئي نتيجة ايجابية في زيادة خشونة السطح حيث ممكن ان تستخدم مستقبلا في عملية تثبيت تركيبات الاسنان.