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Evaluation of the effects of different surface treatments on the bond strength of recent CAD-CAM hybrid ceramics

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Abstract

Aim: The aim of this study was to evaluate the effect of different surface treatments (control, hydrofluoric [HF] acid, sandblasting with Al_2O_3 particles, tribochemical silica coating, and fiber laser) on the surface structure and shear bond strength of ceramics.

Methodology: A total of 120 specimens were used for the evaluation of shear bond strength and 10 specimens for SEM. The ceramics were divided into two groups according to ceramic type and further divided into five subgroups according to surface treatments. SEM images were taken from each group after the surface treatments. Clearfil Ceramic Primer Plus silane was applied to all specimens. Panavia V5 adhesive resin cement was applied to the samples. The bond strength was measured through a shear test using the universal testing machine. A stereomicroscope was used to analyze the surfaces for the failure type. To determine statistical significance, one-way analysis of variance (ANOVA), Tamhane Multiple Comparison, Kruskal-Wallis H, Mann-Whitney U, and Bonferroni-corrected Mann-Whitney U tests were used.

Results: The highest bond strengths were obtained for the groups treated with HF acid and sandblasting with Al_2O_3. The bonding strength values of Vita Enamic were higher than those of Lava Ultimate

Conclusion: HF acid was the best treatment to increase the bond strength between ceramic and cement.

Keywords: Bond strength, CAD-CAM, hybrid ceramic, SEM analysis, surface treatments

Introduction

The minimally invasive treatment approach that has been adopted in dentistry in recent years to protect tooth tissues has eliminated the need to remove large amounts of dental tissues (1). With the use of CAD-CAM technology, which facilitates the construction of indirect restorations in dentistry, allowing restorations that are more suitable for dental anatomy to be produced faster and more easily.

Non-metal restorative materials used in CAD-CAM technology are divided into two main groups: ceramics and composites (2). Ceramics are frequently used because of their aesthetics, biocompatibility, color stability, and good abrasion resistance. However, these materials have a fragile structure and cause abrasion on the opposing teeth. Although composite restorations have aesthetic disadvantages compared to ceramic restorations, they are easier to adapt and cause less wear on the opposing tooth (3). Hybrid ceramic materials that are compatible with CAD-CAM technology and offer the positive properties of composites and ceramics have been developed as alternatives to these materials (4).

The use of adhesive resin cements that allow the adhesion of indirect restorations to the tooth tissue is the most important stage of successful prosthetic treatment. Adhesive resin cements form a tight connection between tooth and indirect restoration and allow the structure to move in fully (5). To form a tight connection with adhesive resin cements, additional surface treatment is required on both the tooth and the inner surface of the restoration. The application of hydrofluoric (HF) acid, sandblasting with Al_2O_3 particles, tribochemical silica coating techniques, and laser applications are some of the current surface roughening processes used for this purpose.

The purpose of this study was to evaluate the effects of different surface treatments (control, hydrofluoric (HF) acid, sandblasting with Al_2O_3 particles, tribochemical silica coating, and fiber laser) on the surface structure and shear bond strength of ceramics.

Materials and Methods

Samples were obtained by cutting the connecting surfaces of the ceramic block so that the outer cylindrical mold, which was 2.2 cm in diameter and 2 cm in height, was fixed by pouring into a transparent self-curing acrylic resin (Imicryl, Konya, Türkiye). Next, 400, 600, and 1000 grit silicon carbide water sanders (3M™, Wetordry™, 3M, St. Paul, MN, USA) were applied to the outer connection surfaces of the samples. All samples were then stored in an ultrasonic cleaner containing saline for 10 min.

The samples were subjected to different surface roughening processes, resulting in the creation of ten groups, each containing 12 samples. Five samples of Lava Ultimate and five Vita Enamic ceramics were used in the SEM analysis to compare the roughness values of the groups (Table 1). State sample sizes were determined with power analysis.

For the control group, surface roughening was applied to the surface of the hybrid ceramics as suggested by the manufacturer of the Panavia V5 adhesive resin cements. The K_ETCHANT syringe containing 35% phosphoric acid was applied to the ceramic surface for 5 s. The surface was washed with pressurized water for 5 s and then dried with air spray.

For the HF acid group, 9.6% HF acid was applied to the ceramic surface for 60 s, washed with pressurized water for 60 s, and then dried with air spray. The Clearfil Ceramic Primer Plus silane in the cement set was applied to connect the Panavia V5 adhesive resin cement to the ceramic surface. The silane was left for 60 s and then dried.

For the Al_2O_3 group, a simple mechanism comprising a housing to which the samples can sit was formed in order to apply sandblasting to all samples at a distance of 10 mm. Then, 50 µm-sized Al_2O_3 particles were applied to the ceramic surface for 20 s.

For the CoJet group, silica-coated Al_2O_3 particles 30 µm in size were applied using a CoJet sandblaster for 3 s at a pressure of 3 bar. During this process, the distance between the CoJet sandblasting device and the ceramic sample was adjusted to 10 mm.

After these procedures, Clearfil Ceramic Primer Plus silane was applied to each group in order to bind the Panavia V5 adhesive resin cement to the ceramic surface. The silane was left for 60 s and then dried using oil-free dry air.

For the laser group, there was no appropriate parameter in the literature regarding the roughening of the Yb:fiber laser hybrid ceramic surface. Therefore, a pilot study was conducted to find the appropriate parameters that could be applied first: 5 watt/25 kHz, 5 watt/40 kHz, 5 watt/60 kHz, and 5 watt/80 kHz. After laser application with these parameters, it was decided that the sample roughened with 5 watts/40 kHz laser power was the most suitable for SEM examination.

For the bonding of adhesive resin cement to the ceramic samples, Panavia V5 adhesive resin cement was applied to the prepared mold, and pre-polymerization was performed with an LED light device in 1 mm layers for 20 s. After removing the Teflon parts, two different surfaces of the samples were polymerized for 20 s. All samples prepared in this manner were stored in distilled water at room temperature for 24 h. All samples were subjected to thermal cycling in a thermal cycle device 5000 times. The universal tester then applied a separation force of 0.5 mm/min to the attachment interface. The ceramic-resin cement was examined using a stereomicroscope to determine the fracture types.

The breaking types are;

- **Type I:** Adhesive breakage (resin cement block rupture from the ceramic)
- **Type II:** Cohesive breakage (rupture of the ceramic or resin cement block itself)
- **Type III:** Mixed breakage (adhesive and cohesive breakage at the same time).

After the samples to be examined were fixed on the aluminum block with adhesive tape, the sample surfaces were covered with a gold-palladium mixture of 135 A° thickness using an SC 7620 Mini Sputter Coater. The samples were then fixed to the SEM device with double-sided tape holders, and surface images were taken at 500X, 1.00 KX, 2.00 KX, 5.00 KX, 10.00 KX, and 20.00 KX magnifications.

Statistical analysis

Analyses were performed using the SPSS software (IBM SPSS Statistics version 21.0, IBM Inc., Armonk, NY, USA).

A one-way ANOVA, Tamhane multiple comparison, Kruskal-Wallis H, Mann-Whitney U, and Mann-Whitney U tests with Bonferroni correction were used for statistical analysis. The hypotheses were bidirectional, and $p<0.05$ was considered statistically significant.

Table 1. Materials used in the study.

Material	Ingredient	Manufacturer
Lava Ultimate A2LT (Resin nanoceramic hybrid)	Resin bound to matrix 80% nanoceramic hybrid with particles one block. Filler, 20 nm silica. clustered zirconia/silica combination	3M ESPE Dental Products. St. Paul, MN, USA
VITA Enamic 1M2T (Hybrid Ceramic block)	Aluminum Oxidized reinforced feldspathic ceramic	VITA Zahnfabrik, Bad Sackingen, Germany
CoJet sandblaster particles	Alumina modified with silicic acid 30 µm particles	3M ESPE Dental Products. St. Paul, MN, USA
Korox 50	Al_2O_3 particles of 50 µm at a rate of 99.6%	Treibacher, Schleifmittel, Italy
HF acid	%9.6 HF acid	Dicle University, Department of Chemistry, Diyarbakır, Türkiye
Panavia V5 (Adhesive resin cement set)	Pastry A. Pastry B. stirrer special tip and Clearfil Ceramic Primer Plus	Kuraray Noritake Dental Inc. Okayama, Japan

Results

Shear test findings

In this study, the adhesive shear bonding resistance values of Lava Ultimate and Vita Enamic hybrid ceramic samples with five different surface treatments were measured. The Lava Ultimate and Vita Enamic hybrid ceramic samples were examined for shear bond strength with adhesive resin. The highest value was observed in the Vita Enamic ceramic group, which was sandblasted with Al_2O_3 particles (26.92 MPa). The lowest value was found in the Lava Ultimate ceramic group (0.52 MPa) with surface roughening by a fiber laser (Table 2).

There was a statistically significant difference between the shear bond strengths of Lava Ultimate and Vita Enamic ceramic materials ($p<0.05$). The bond strength of Vita Enamic ceramic material was significantly greater than that of Lava Ultimate ceramic material (Tables 3 and 4).

Table 2. Comparison of bond strengths according to ceramic material.

Ceramic Material	Shear bond strength Median (Min-Max)	Mean±SD	*P*
Lava Ultimate	5.91 (0.53-22.59)	7.92±6.91	0.011
Vita Enamic	9.61 (1.36-26.92)	10.33±6.31	

Table 3. Comparison of bond strengths according to the surface treatment.

Surface Treatment	Shear bond strength Mean±SD	Median (Min-Max)	*P*
Control	7.36±4.95	6.09 (1.86-22.59)	**0.000**
HF acid	15.79±4.86	16.98 (6.70-22.60)	
Al_2O_3	12.83±6.86	11.18 (2.97-26.92)	
CoJet	7.26±4.41	8.23 (0.91-15.53)	
Laser	2.41±1.77	1.83 (0.53-7.86)	

Table 4. Comparison of average shear bond strengths of Lava Ultimate and Vita Enamic ceramic materials in surface treatment groups.

	Shear bond strength				
	Lava Ultimate		Vita Enamic		
Surface Treatment	Mean±SD	Median (Min-Max)	Mean±SD	Median (Min-Max)	*p*
Control	6.84±5.27	5.91 (2.20-22.59)	7.89±4.77	6.66 (1.86-16.37)	0.386
HF acid	17.16±4.80	19.24 (7.86-22.54	14.41±4.73	13.81(6.70-22.60)	0.204
Al_2O_3	10.43±5.56	9.62(2.97-21.54)	15.22±7.41	15.95(3.86-26.92)	0.094
CoJet	3.80±2.72	3.08 (0.91-8.79)	10.73±2.66	10.91(5.04-15.53)	**0.000**
Laser	1.39±0.85	1.15 (0.53-3.28	3.43±1.90	3.36 (1.36-7.86)	**0.002**

There was a statistically significant difference between the bonding resistances according to the applied surface treatment (p=0.001). The binding resistance of the laser group was significantly lower than that of the other groups (p=0.001). The binding resistance of the HF acid-treated group was significantly greater than that of the control and CoJet-treated groups (p=0.001). There was no statistically significant difference between the binding resistance of the Al_2O_3 group and that of the HF acid and CoJet groups (p=0.05). The difference between the binding resistance of the control group and the resistance of the control group was statistically significant (p=0.05). No statistically significant difference was observed between the CoJet and control groups (p=0.05).

No statistically significant difference was found between the shear bond strengths of Lava Ultimate and Vita Enamic ceramic samples treated with HF acid and Al2O3 and that of the control group (p=0.005). The difference between the shear bond strengths of the Lava Ultimate and Vita Enamic ceramic samples applied CoJet and laser was statistically significant (p=0.005) (Table 5).

Table 5. Comparison of bonding resistance of ceramic materials according to surface treatment.

	Shear bond strength			
	Lava Ultimate		Vita Enamic	
Surface Treatment	Mean±SD	Median (Min-Max)	Mean±SD	Median (Min-Max)
Control	6.84±5.27	5.91 (2.20-22.59)	7.89±4.77	**6.66 (1.86-16.37)**
HF acid	17.16±4.80	19.24 (7.86-22.54)	14.41±4.73	**13.81(6.70-22.60)**
Al_2O_3	10.43±5.56	9.62 (2.97-21.54)	15.22±7.41	**15.95(3.86-26.92)**
CoJet	3.80±2.72	3.08 (0.91-8.79)	10.73±2.66	**10.91(5.04-15.53)**
Laser	1.39±0.85	1.15 (0.53-3.28)	3.43±1.90	**3.36(1.36-7.86)**
P	0.000		0.000	

There were statistically significant differences between the bonding resistance of the Lava Ultimate ceramic samples according to the surface treatment (p=0.001). The binding resistance of the laser group was significantly lower than that of all other groups (p=0.005). The binding resistance of the HF acid group was significantly greater than that of the control and CoJet groups (p=0.005). There was no statistically significant difference between the binding resistance of the HF acid and Al_2O_3 groups (p=0.005). The shear bond strength of the group treated with Al_2O_3 was significantly greater than that of the CoJet group (p=0.005).

There was a statistically significant difference between the bonding resistance of the Vita Enamic ceramic material according to surface treatment (p=0.001). The binding resistance of the laser group was significantly lower than that of all other groups (p=0.005). There was no statistically significant difference between the binding resistance of all other groups (p=0.005).

Stereomicroscope examination

After the shear test, 120 samples were examined. Type I ruptures (81.7%), Type II ruptures (3.3%), and Type III ruptures (15%) were observed in four of the 98 samples. Based on this, the most common rupture type was adhesive breakage, whereas the least common rupture type was cohesive breakage. The breakage types were compared based on the surface treatment. Only adhesive-type ruptures were observed in the control, CoJet, and laser groups. Cohesive-type ruptures were observed only in the HF acid group. Mixed-type ruptures were observed in the HF acid and Al_2O_3 groups. Mixed-type ruptures were most common in the HF acid group.

The rupture types of the ceramic materials were compared. The most common rupture in both Lava Ultimate and Vita Enamic ceramic samples was breakage. Cohesive breakage was observed only in the Vita Enamic ceramic material. Mixed breakage was observed mostly in the Vita Enamic ceramic material.

SEM findings

In the SEM images of the Lava Ultimate and Vita Enamic ceramics included in the control group, pits formed by the application of phosphoric acid on the ceramic surfaces were observed (Figs. 1, 2). In the SEM images of the HF acid group, it was observed that the indices and irregularities formed by HF acid were quite high and more complex compared to the other groups (Figs. 3, 4). The SEM images of the ceramic surfaces of the Al_2O_3 group revealed the presence of recesses and irregularities formed by Al_2O_3 particles, and these particles remained between these irregular structures (Fig. 5, 6). In the SEM images of the ceramic surfaces of the CoJet group, it was observed that there were indentations and irregularities formed by silica Al_2O_3 particles, and these structures were covered with silica particles (Figs. 7, 8).

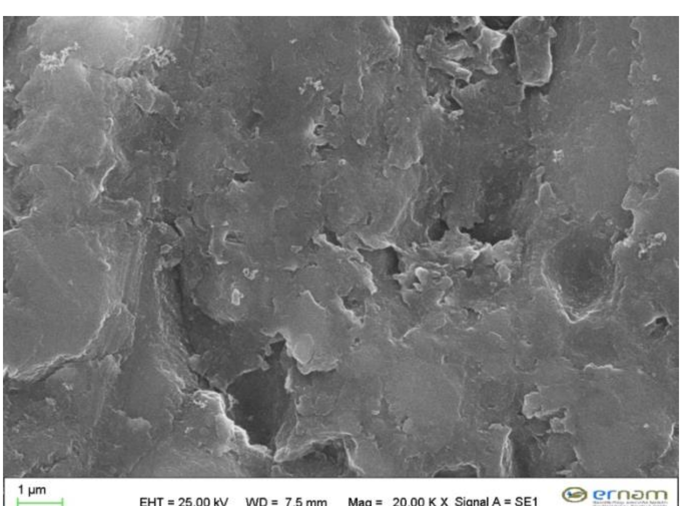

Figure 1. SEM images of ceramic samples (Lava Ultimate) included in the control group (20.00 KX).

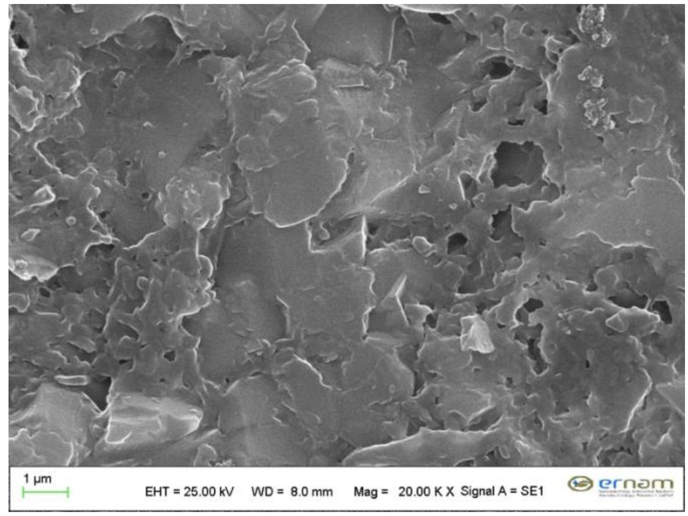

Figure 2. SEM images of ceramic samples (Vita Enamic) included in the control group (20.00 KX).

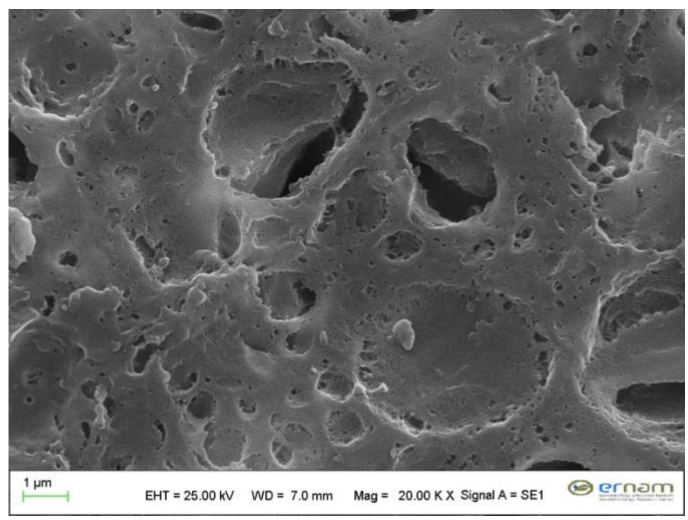

Figure 3. SEM images of ceramic samples (Lava Ultimate) belonging to the HF acid group (20.00 KX).

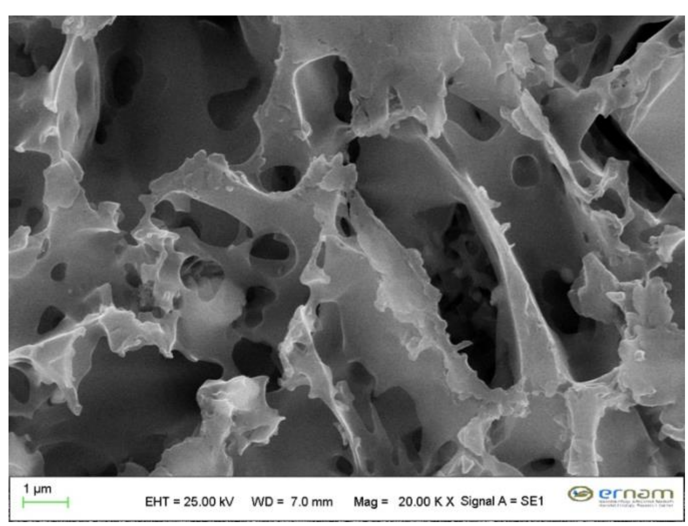

Figure 4. SEM images of ceramic samples (Vita Enamic) belonging to the HF acid group (20.00 KX).

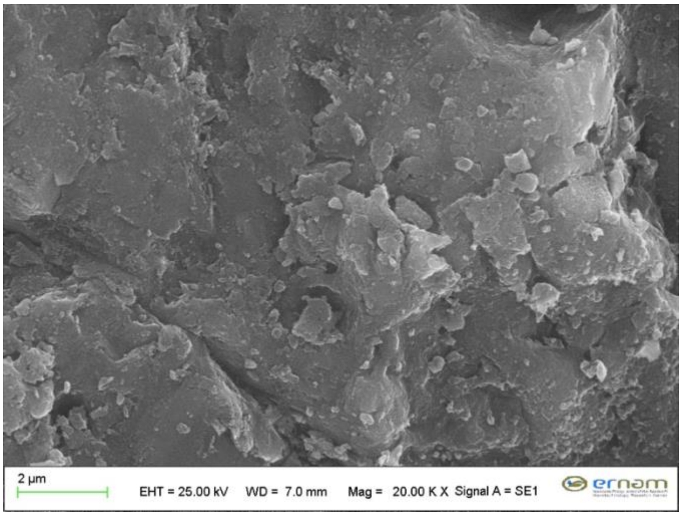

Figure 5. SEM images of ceramic samples (Lava Ultimate) belonging to the Al_2O_3 group (20.00 KX).

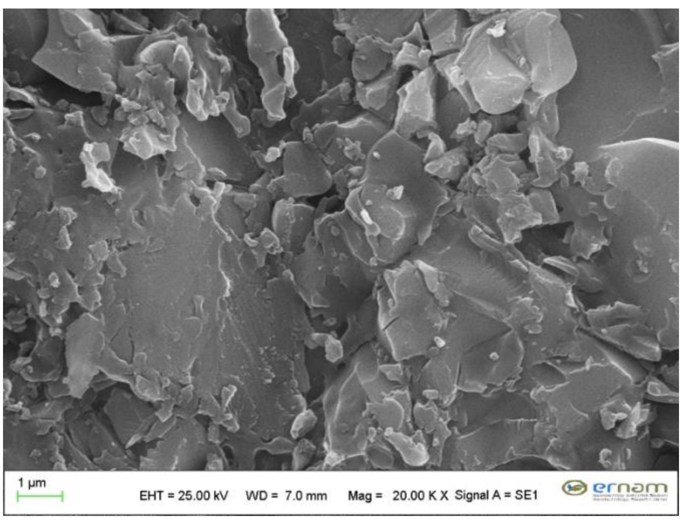

Figure 6. SEM images of ceramic samples (Vita Enamic) belonging to the Al_2O_3 group (20.00 KX).

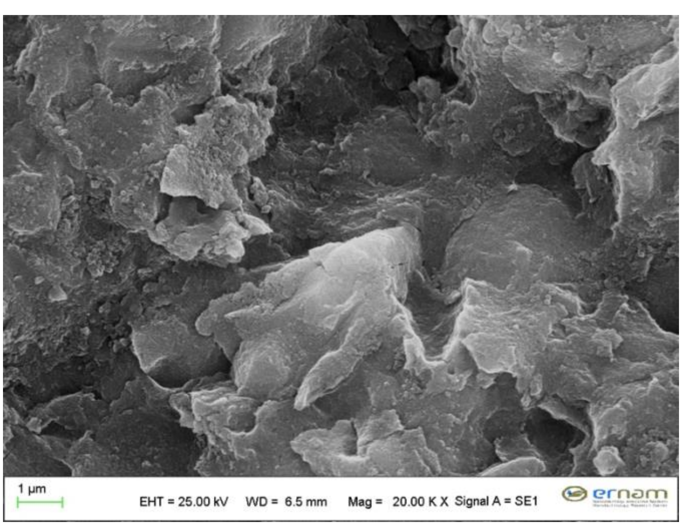

Figure 7. SEM images of ceramic samples (Lava Ultimate) belonging to the CoJet group (20.00 KX).

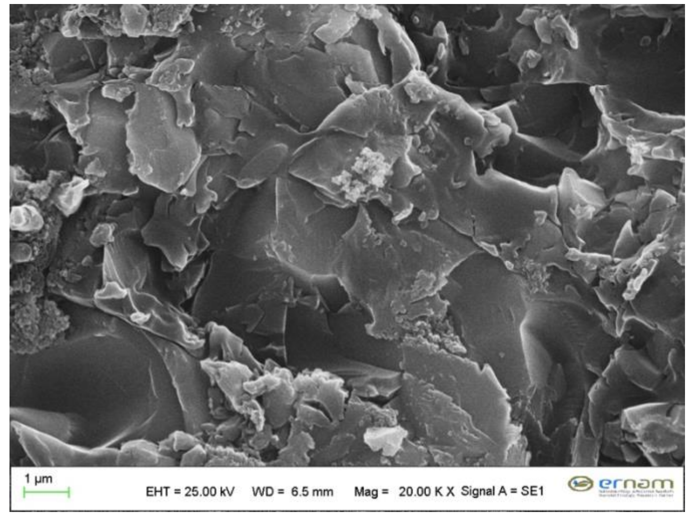

Figure 8. SEM images of ceramic samples (Vita Enamic) belonging to the CoJet group (20.00 KX).

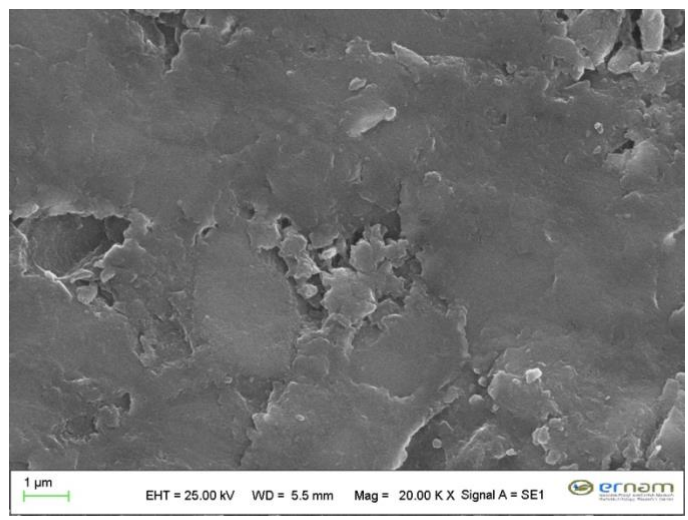

Figure 9. SEM images of ceramic samples (Lava Ultimate) included in the laser group (20.00 KX).

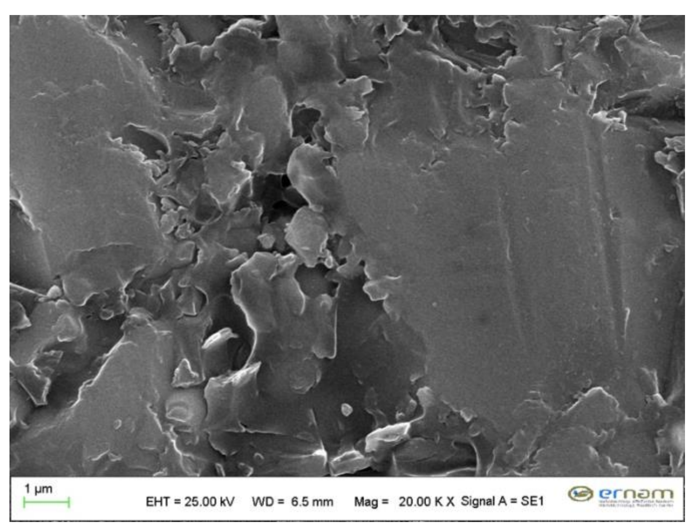

Figure 10. SEM images of ceramic samples (Vita Enamic) included in the laser group (20.00 KX).

The SEM images of the ceramic surfaces of the samples in the laser-applied group revealed irregular areas in the form of recesses and protrusions. In addition, the ablation effect of the laser was observed. However, these indentations were fewer than in the other groups (Figs. 9, 10). In all the groups examined, the surface roughness of Vita Enamic ceramic material was observed more than the surface roughness of Lava Ultimate ceramic material.

Discussion

Hybrid ceramic material, the latest technology used in dentistry, incorporates the best features of composite and ceramic materials. The elastic modulus of the hybrid ceramic material is similar to that of dentin, and its hardness is between that of enamel and dentin. As a result, no abrasions were created on the opposing teeth. Hybrid materials are also easier to adapt, repair, and modify than ceramic materials (6, 7).

Currently, the number of studies that have investigated the properties of hybrid ceramics is limited. One study investigated the bond strengths of Lava Ultimate and Vita Enamic to adhesive resin cement after different surface roughening processes. Della Bona et al. (8) studied the properties of Vita Enamic and found that it consists of interwoven ceramic and polymer network structures. He and Swain (9) obtained similar results, showing that Vita Enamic's mechanical properties are similar to enamel and dentin.

To obtain an accurate bond strength value and ensure that the ceramic specimens embedded in the acrylic mold were not separated from the mold during shear bond testing, a minimum sample thickness of 1.5 mm was required. Considering previous studies, our hybrid ceramic samples were 2 mm thick. The bond strength between the resin and the ceramic surface is based on micromechanical locking and chemical bonding. Various surface treatments are applied to create retention areas on the ceramic surface (10), including hydrofluoric acid roughening and the application of a silane binding agent, which are the most commonly used and recommended methods (11). Some researchers believe that the application of hydrofluoric acid constitutes works best, while others prefer silane-binding agents (12, 13).

When phosphoric acid was used instead of hydrofluoric acid, researchers found that phosphoric acid yielded much shallower retentive areas than hydrofluoric acid, resulting in less binding strength (14, 15). Peumans et al. (16) examined the effect of acid type on bond strength and reported that hydrofluoric acid significantly increased bond strength compared with phosphoric acid. El-Damanhoury and Gaintantzopoulou (17) reported that the application of hydrofluoric acid followed by a silane binding agent is the gold standard for roughening ceramics containing glass.

Another effective method for providing roughness is blasting different sizes of Al_2O_3 particles at a surface using a certain pressure (18). Kassotakis et al. (19) and Frankenberger et al. (20) demonstrated that the Al_2O_3 particle blasting technique is the most effective method for roughening hybrid ceramic materials. In tribochemical silica coating systems, a silica layer is formed when Al_2O_3 particles coated with silica impact ceramic surfaces at certain pressures and speeds. Silica-coated particles penetrate the ceramic surface and form retentive areas (13, 21, 22). We used a CoJet system to compare surface roughening techniques and perform tribochemical silica coating. Silica-coated Al_2O_3 particles 30 µm in size were applied to our sample ceramic surfaces for 20 s from a distance of 10 mm.

Various lasers have been used in surface roughening processes. In several studies, a ytterbium (Yb) fiber laser was used to roughen zirconium (Zr) material, increasing the material's bond strength (23,24). However, this method has not been used to roughen any porcelain systems other than Zr. To overcome this gap in the literature, we evaluated the effect of a 5 W 40 kHz Yb fiber laser on hybrid ceramic samples.

Our results showed that the bond strength, from greatest to least, was observed after using hydrofluoric acid, Al_2O_3 particles, and laser particles. No significant differences were observed between the hydrofluoric acid and Al_2O_3 particle blasting groups. Similar to our study, Stawarczyk et al. (25) observed that the hydrofluoric acid group exhibited a higher bond strength, but the difference was not statistically significant. Bankoğlu Güngör et al. (26) investigated the bond strength between composite resin and Lava Ultimate, Vita Enamic, and GC Cerasmart, finding that not only was the bond strength after Al_2O_3 blasting greater than the hydrofluoric acid group, but that there was also a significant difference between the groups. Because we used adhesive resin cement, a direct comparison could not be made, which may explain the difference in the results.

In our study, the hydrofluoric acid group and Lava Ultimate exhibited greater bond strength than blasting Al_2O_3 particles and Lava Ultimate, but the group with Al_2O_3 particles displayed greater bond strength with Vita Enamic than the hydrofluoric acid group did. However, no significant differences were found between these two groups in either ceramic material. Contrary to our thesis, Frankenberg et al. (20) proposed roughening Lava Ultimate ceramic material with Al_2O_3 particles and Vita Enamic using hydrofluoric acid. Duzyol et al. (22) also proposed roughening Lava Ultimate with Al_2O_3 particles. SEM examination in our study revealed that Vita Enamic, roughened with hydrofluoric acid, appeared to have a spongy structure. This spongy structure may have adversely affected the bond between the adhesive resin cement and the ceramic sample.

Our study found that the CoJet roughness group had lower bond strength values than the groups with hydrofluoric acid roughening and sandblasting with Al_2O_3 particles. Duzyol et al. (22) used Lava Ultimate ceramic material in their work and found that sandblasting with Al_2O_3 was higher than the 5% hydrofluoric acid and CoJet groups, and there was no significant difference between the 5% hydrofluoric acid and CoJet groups. The fact that the results of this study do not parallel our study may be due to the different concentrations of hydrofluoric acid used. Barutcigil et al. (3) used Vita Enamic ceramic material in their work and stated that the bond strength values of the CoJet group were lower than hydrofluoric acid, sandblasting with 50 µm Al_2O_3 particles, and Er. Cr: YSGG laser roughening groups. It was reported that the bond strength values of the CoJet group were lower than those of shot-blasting with hydrofluoric acid and 50 µm Al_2O_3 particles, in line with our study. Elsaka (27) evaluated the bond strength of metal and ceramic brackets to the Vita Enamic ceramic material and used 9% hydrofluoric acid for 60 s, 37% phosphoric acid for 60 s, and a 4-sec CoJet application. According to their results, unlike our study, the bond strength values of the CoJet-roughened group were found to be higher than those of the other groups. This result can be attributed to the use of composite resin instead of adhesive resin cement in the connection.

In this study, the bond strength values of the control group were higher than the bond strength values of the CoJet and laser groups. No statistically significant difference was observed between the control, CoJet, and laser groups in Vita Enamic ceramic material. In the Lava Ultimate ceramic material, there was no statistically significant difference between the control and CoJet groups; however, a significant difference was observed between the control and laser groups. In the control group, 37% phosphoric acid was applied for 5 s, as recommended for hybrid ceramics, in the Panavia V5 adhesive resin cement set. Therefore, the bond strength values in the control group may be higher than in the CoJet and laser groups.

In our study, the fiber laser group exhibited the lowest binding strength values. Fiber lasers have previously been used for the surface roughening of zirconium materials, and successful results have been achieved. However, the application of fiber lasers to hybrid ceramic materials has not been investigated in previous studies. In our study, the fiber laser dose used was 5 W/40 kHz. According to the results of this study, the low values of this group may depend on the laser dose used. In addition, the contents of zirconium and hybrid ceramic materials differed from each other. This may be another reason for the failure of the fiber laser on the hybrid ceramics.

According to our results, the bond strength values of Vita Enamic were higher than those of Lava Ultimate, possibly due to the differences in the inorganic structure content of the materials. Lauvahutanon et al. (28), in their study investigating the content of Vita Enamic ceramic material, including the mechanical properties of inorganic filler materials and ceramic materials, found that it was higher than Lava Ultimate ceramic material. Miyazaki et al. (29) investigated the relationship between the bond strength and filler content of ceramic materials and reported that increased filler content causes higher bond strength. In our study, the bond strength values were parallel to those of these studies. The microstructures of Lava Ultimate and Vita Enamic ceramic materials also differ. Lava Ultimate is a ceramic material with a resin matrix structure supported by fillers. Vita Enamic consists of interpenetrating plexus structures within the resin matrix (9, 30). During the thermal cycling process, the Lava Ultimate material containing the resin matrix supplemented with fillers may have absorbed more water. In this case, it can be said that microstructural differences are caused by a significant difference between the bond strength results. Another reason why Lava Ultimate ceramic specimens showed lower bond strength values may be the presence of zirconium particles in the material content (30). Zirconium particles in the structure can cause connection problems.

Conclusion

In summary, one of the most important factors affecting the bonding strength of ceramic-adhesive resin is the surface treatment applied to the ceramic surface. The preferred method for roughening the ceramic surface is the application of hydrofluoric acid. Although it produces effective roughening of the ceramic surface and is easy to apply, accidental hydrofluoric acid in the mouth can have dangerous consequences. Therefore, alternative surface roughening techniques are being investigated. After evaluating the bond strength values obtained by the shear test and the rupture types examined by the stereomicroscope, we can conclude that blasting with hydrofluoric acid and Al_2O_3 particles is the most effective method. To provide reliable information for clinicians, this study was conducted under laboratory conditions providing standardization and should be validated with long-term clinical studies.

Disclosures

Peer-review: Externally peer-reviewed.

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