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The Effect of Fractional CO2 Laser Irradiation on Shear Bond Strength of Resin Cement to Feldspathic Porcelain

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Abstract

Introduction: This study investigated the effect of fractional CO2 laser on shear bond strength (SBS) of resin cement to feldspathic porcelain.

Methods: Sixty blocks of unglazed feldspathic porcelain were randomly divided into 5 groups of 12 by treatment. Group 1 and 2 underwent etching with 9.6% hydrofluoric acid (HF) and air abrasion with alumina particles, respectively. In groups 3 and 4, a fractional CO2 laser was applied for 10 seconds using 20 W/10 mJ (group 3) or 15 W/20 mJ (group 4). The specimens in group 5 were first treated by fractional CO2 laser (15 W/20 mJ) and then etched by HF acid. After silane application, a resin cement (Clearfil SA) was poured into plastic molds over the porcelain surface and light cured. SBS was assessed by a universal testing machine and the type of bond failure was determined.

Results: Analysis of variance (ANOVA) indicated a significant difference in SBS among the study groups ($P<0.001$). Pairwise comparison demonstrated that the application of fractional CO2 laser followed by HF acid yielded SBS that was significantly greater than that of the other groups ($P<0.05$). The SBS of both laser groups (groups 3 and 4) were comparable to each other and significantly lower than the other groups ($P<0.05$). No significant difference was found in the distribution of failure modes among the groups ($P=0.522$)

Conclusion: The application of fractional CO2 laser followed by HF acid treatment can improve SBS of resin cement to feldspathic porcelain and could be recommended when demanding extra retention.

Keywords: Acid etching; Air abrasion; Bond strength; CO2 laser; Feldspathic porcelain.

Introduction

Feldspathic porcelains are widely used in dentistry for fabrication of porcelain veneers or layering of full-ceramic or metal-ceramic crowns. Porcelain veneers are generally employed for esthetic rehabilitation of discolored teeth, incisal fractures or diasthema closure.[1-3] The retention of porcelain veneers depends on the appropriate adhesion to the remaining tooth structures and thus, creating a suitable bond plays a great role in long-term success of these restorations.[4] Feldspathic porcelains are also commonly used as the veneering layer of full-ceramic or metal-ceramic crowns due to their esthetic appearance, biocompatibility and corrosion resistance.[5,6] Chipping of the feldspathic layer frequently occurs in clinical conditions and is among the main reasons for failure of these crowns.[7,8] Although replacement of chipped restorations is the most recommended procedure, in some situations, porcelain repair could be considered as an alternative treatment. This treatment option requires the use of surface conditioning methods in order to provide sufficiently high bond strength between composite and feldspathic layers.

Various methods have been suggested to improve bond strength of resin composites or resin cements to feldspathic porcelain, such as etching with hydrofluoric acid (HF), silane application, sandblasting, or laser irradiation.[9-12] It has been demonstrated that silane treatment can improve bond strength by creating a chemical bond between porcelain and composite. However, the chemical bond is prone to hydrolytic degradation,[13,14] which may affect the long-term success of restorations. The mechanical or micromechanical retention can be achieved via the application of HF acid, sandblasting or laser irradiation. Several studies demonstrated that etching with HF acid can provide sufficient bond strength, but this procedure may have hazardous effects on oral soft tissues and is also

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time-consuming.[15,16]

Surface conditioning of tooth structures or dental materials is among the main applications of lasers in dentistry.[17-20] Different devices such as Er:YAG, Nd:YAG and conventional CO2 lasers can be used for conditioning ceramic substrates.[21-23] Another option is the use of fractional CO2 laser. The concept of fractional photothermolysis was introduced in recent years in order to reduce the side effects of skin resurfacing with ablative CO2 and Er:YAG lasers such as burning, prolonged downtime, edema, and scarring.[12,24] In contrast to the conventional methods, which create layers of thermal heating, fractional CO2 laser produces multiple columns of microscopic thermal wounds (microscopic treatment zones), while the surrounding tissues remain healthy and untreated, and thus supporting the wound healing process. We believe that the use of fractional CO2 laser could be associated with several advantages in dentistry. It can allow the clinician to predetermine the treatment area, where the laser irradiates multiple zones with predefined space between them. In this way, there would be no need for manual movement of the laser handpiece by the clinician, and therefore a more homogenous etching pattern would be attained on the surface.[12] Furthermore, the risk of thermal damage to the underlying tissues would be minimized.[12]

There are some studies on the use of conventional CO2 laser and few studies on the use of fractional CO2 laser for improving the bond strength of resin composites or resin cements to different types of ceramic. The aim of this study was to evaluate the efficacy of fractional CO2 laser irradiation on SBS of resin cement to unglazed feldspathic porcelain and compare the results with that of HF acid treatment and air abrasion. The null hypothesis of this study was that the application of fractional CO2 laser would not enhance bond strength of resin cement to feldspathic porcelain.

Methods

Sixty blocks of unglazed feldspathic porcelain (Vita, Bad Sackingen, Germany) measuring 8×8×5 mm were fabricated according to the manufacturer's instructions. The specimens were evaluated to discard those with cracks or surface defects and then mounted horizontally in self-cured acrylic blocks. The surfaces of the specimens were cleaned with ethyl alcohol and the specimens were randomly divided into 5 groups of 12, according to the surface treatment method applied before the cementation process.

In group 1 (control), the samples were etched by 9.6 % HF acid (Porcelain Etch Gel, Pulpdent Corp., Watertown, MA, USA) for 2 minutes, rinsed thoroughly with distilled water and air-dried.

The specimens in group 2 were subjected to air abrasion with 50 µm aluminum oxide (Al2O3) particles, which was applied for 15 seconds at 2.5 bar pressure. The device was held perpendicularly at a 10 mm distance to the ceramic surface. The surfaces of the specimens were rinsed under running tap water to remove aluminum oxide particles and air dried.

In groups 3 and 4, the specimens were treated with a fractional CO2 laser (wavelength 10.6 µm, Lutronic Inc., Princeton Junction, NJ, USA) (Figure 1). The laser device was run in dynamic mode and set up to irradiate a square area measuring 4 mm × 4 mm at the center of the specimen. The laser tip was held manually at 3 cm distance and perpendicular to the surface, and the irradiation was performed for 10 seconds per specimen. A 200 Hz frequency (pulse per second) was selected in both laser groups. The choice of power and energy were 20 W/10 mJ and 15 W/ 20 mJ in groups 3 and 4, respectively. These parameters were taken from previous studies,[12,25] and the results of our pilot study (data have not been presented) to find the parameters that etch the feldspathic porcelain without creating visible thermal damage.

The surfaces of the specimens in group 5 were first irradiated with the fractional CO2 laser under the same conditions as described in group 4 (15 W/20 mJ) and then treated with 9.6% HF acid for 2 minutes, similar to the control group.

After the surface treatment procedures described in groups 1 to 5, a silane coupling agent (Silane bond enhancer, Pulpdent Corp., Watertown, MA, USA) was applied on the surface with a disposable applicator and remained to dry for 1 minute. The resin cement (Clearfil SA; Kurary, Kurashiki, Okayama, Japan) was prepared according to the manufacturer's instructions. The cement was then poured into plastic molds measuring 1.5 mm in diameter and 2 mm in height placed over the ceramic surfaces. The excess cement was removed from the periphery of the mold with an explorer and the cement was then polymerized for 40 seconds from 4 opposite

Figure 1. Fractional CO2 Laser Used in This Study.

directions (10 seconds each) using a light emitting diode (LED) unit (Blue phase C8, Ivoclar Vivadent, Schaan, Liechtenstein) at a power density of 650 mW/cm^2.

After 30 minutes, the plastic molds were cut and carefully removed and the specimens were kept in distilled water at room temperature for 24 hours. The samples were then subjected to shear bond strength (SBS) test. The SBS test was performed by an Instron universal testing machine (Santam, model STM-20, Iran) at a cross-head speed of 1 mm/min. The failure load was recorded in Newtons and then converted to megapascals (MPa) by dividing the load by the bonding area (mm^2).

After SBS test, the fractured interfaces were evaluated at 10X magnification using a stereomicroscope (LEO, 1450 UP, Zeiss; Oberkochen, Germany) to determine the type of bond failure using the following classification:

Adhesive: failure at the interface of the luting cement and ceramic

Cohesive: failure inside the resin cement or ceramic

Mixed: a combination of adhesive and cohesive failures

Statistical Analysis

The normal distribution of the data was confirmed by the Kolmogorov-Smirnov test. One-way analysis of variance (ANOVA) was run to detect any significant difference in SBS among the study groups followed by Duncan post hoc test for pairwise comparisons. The difference in the mode of bond failure among the groups was determined by Fisher's exact test. The data were processed using SPSS software (version 11.5, SPSS Inc. Chicago, IL) and the level of significance was set at $P<0.05$.

Results

Table 1 presents the means and standard deviations (SDs) regarding SBS values (MPa) of the experimental groups. The greatest bond strength was observed in group 5 where the combination of fractional CO2 laser and HF acid was applied on the surface and the lowest one was observed in group 3 with the use of fractional CO2 laser at a setting of 20 W/10 mJ (Table 1).

ANOVA indicated a significant difference in SBS among the study groups ($P<0.001$; Table 1). Pairwise comparison by Duncan test demonstrated that the application of CO2 laser followed by HF acid (group 5) yielded bond strength that was significantly greater than that of the other groups ($P<0.05$). The next SBS pertained to the specimens treated with HF acid, which showed significantly greater SBS than all other groups except group 5 ($P<0.05$). The bond strengths of both laser groups (groups 3 and 4) were comparable to each other and significantly lower than that of the other study groups ($P<0.05$).

Table 2 indicates the frequency of failure modes in the samples. The most frequent failure in all groups was adhesive fracture. The mixed and cohesive failure modes were also observed in a small percentage of the specimens (Table 2). Fisher exact test revealed no significant difference in the distribution of failure modes among the groups ($P=0.522$).

Discussion

The outcomes of this study indicated that the application of fractional CO2 laser cannot improve the bond strength of resin cement to feldspathic porcelain, confirming the null hypothesis of the study. However, the application of fractional CO2 laser followed by HF acid treatment was indeed effective in enhancing the bond strength, as it produced SBS value that was significantly greater than that of the other study groups. The self-adhesive cement used in this study contains 10-MDP monomer. This monomer can promote chemical reaction with tooth structure and some type of ceramics. It should be noted that the application of glaze on the surface of ceramic may affect the surface topography and thus influence the bond strength. In the current study, deglazed samples were used in order to simulate the internal surface of feldspathic veneers or chipped feldspathic porcelains needing repair. A recent study[12] found that fractional CO2 laser has better performance when used on deglazed than glazed feldspathic porcelain for bonding metal orthodontic brackets. However, Zarif Najafi et al[26] concluded that deglazing is not a mandatory step before application of CO2 laser for surface preparation of feldspathic porcelain. In the present study, the use of HF acid provided bond strength value that was significantly greater than that of the air-abraded and laser-treated specimens. Similarly, other researches demonstrated the effectiveness of HF acid as a surface treatment method for feldspathic porcelain.[16,22,23,27,28] However, the application of HF acid intraorally may be associated with hazardous effects on soft tissues and should be performed with caution.

In the current study, the bond strength of the air

Table 1. The Mean, Standard Deviation (SD) and the Results of Statistical Analysis Regarding Shear Bond Strength (MPa) of the Experimental Groups

Group	Definitions	Mean	SD	Range	Pairwise Comparison
1	Control	17.3	3.03	12.7-21.7	c
2	Air abrasion	15.2	2.52	12.2-20.5	b
3	CO2 laser 20 W/10 mJ	5.9	6.92	4.4-7.9	a
4	CO2 laser 15 W/20 mJ	6.5	1.46	4.4-8.5	a
5	CO2 laser 15 W/20 mJ + HF acid	21.0	3.23	16.5-27	d
Statistical significance		P<0.001			

SD: standard deviation. *Duncan pairwise comparison test; the groups that have been marked with different letters denote statistically significant difference at P < 0.05, whereas those with the same letter are statistically comparable.

Table 2. The Distribution of Failure Modes in the Experimental Groups

Groups	Adhesive	Cohesive	Mixed
Control	13	0	2
Air abrasion	11	1	3
CO2 laser 20 w/ 10 mJ	13	0	2
CO2 laser 15 W/20 mJ	12	1	2
CO2 laser 15 W/20 mJ+ HF acid	9	2	4

abrasion group was significantly lower than that of the control (HF acid) and laser + HF acid groups. Some studies demonstrated that air abrasion by Al_2O_3 particles can increase bond strength to porcelain surface via creating surface roughness and increasing surface area for bonding.[27-29] Others believe that sandblasting may create surface damage in porcelain substrate and lead to reduction in flexural strength of ceramics.[3,30] However, a literature review concluded that air abrasion was a clinically effective method that did not increase ceramic fractures up to 15 years follow-up.[2]

The wavelength of the CO2 laser is greatly absorbed by ceramics, making this laser suitable for ceramic surface treatment.[15, 29-32] However, the use of fractional CO2 laser in the present investigation was not effective in enhancing bond strength to feldspathic porcelain. This finding is in agreement with the results of several authors who reported that the application of CO2 laser[16,22,23,28] could not improve bond strength to feldspathic porcelain in comparison with the use of HF acid. In contrast, some studies reported that laser irradiation can improve bonding of resin materials to porcelains by creating a rough surface and micromechanical retention.[22,23,33] Pedrazzi et al[28] proposed that laser application could condition porcelain surface deeper than other surface treatments and thus improve the resin penetration.

The differences between the results of the current study and those of previous authors could be attributed to the use of different types of ceramics, various laser wavelengths, and diverse laser parameters. The type of ceramic has an important role in surface changes induced by laser devices.[16] Ersu et al[34] applied CO2 laser with the same parameters for surface treatment of three types of ceramic (In-Ceram Spinel, In-Ceram Alumina, In-Ceram Zirconia) and compared the resultant bond strength with conventional methods such as air abrasion and HF acid treatment. They concluded that CO2 laser could provide the highest bond strength in In-Ceram Spinel group while in In-Ceram Alumina no significant difference was found among various surface treatments.

The laser settings applied in this study were selected according to the results of previous studies[12,25] and the results of our pilot study to find the minimum laser parameters that can etch the porcelain surface. Some studies reported increased surface roughness after the use of different lasers for surface conditioning of ceramics. However, Ersu et al[34] found that there is no relationship between the surface roughness of treated porcelain and the bond strength of resin composite to the surface. Although the fractional CO2 laser was not effective in improving the bond strength in this experiment, it is possible that alterations in laser parameters such as power, pulse energy, pulse frequency and pulse duration could improve the bond strength, so further studies are suggested for testing various laser parameters.

In the present study, the application of fractional CO2 laser followed by HF acid provided significantly greater bond strength than HF acid etching, laser irradiation or air abrasion. This method can be recommended when extra retention is required for bonding porcelain veneers or repairing chipped feldspathic porcelains. In contrast to the findings of this study, Alkil et al[21] reported that the use of HF acid after laser irradiation increased SBS of resin composite to feldspathic porcelain, but the resultant bond strength was still lower than that achieved by the application of HF acid alone.

The most frequent failure mode observed in all the study groups was adhesive fracture. The frequency of cohesive and mixed failures was a little greater in group 5, where the highest bond strength was obtained, compared to the other groups. Despite the significant differences observed in bond strength among the experimental groups, the difference in failure modes was not significant. This indicates that bond strength is not the main factor that affects the failure mode, and other factors can also influence the fracture interface.[35,36]

It is believed that bond strength value should be equal or greater than 20 MPa to be clinically acceptable, regardless of the test type employed.[37] Based on the results of the current study, the application of fractional CO2 laser followed by HF acid treatment can provide sufficient bond strength between self-adhesive cement and feldspathic porcelain and is expected to provide long-lasting bonding in the clinical condition.

The current study evaluated in vitro bond strength and so the results cannot be directly applied to the clinical conditions. Therefore, further clinical studies are warranted to evaluate the performance of these surface treatment strategies in long-term follow-ups.

Conclusion

With the limitations of this in vitro study, the following conclusions can be drawn:

- The application of fractional CO2 laser was not capable to improve bond strength of resin cement to feldspathic porcelain.
- The combination of fractional CO2 laser irradiation followed by HF acid treatment provided the greatest bond strength compared to the other methods and could be recommended when extra retention to feldspathic porcelain is required.

Conflict of Interests

None.

Ethical Considerations

None to be declared.

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