



Effects of Different Laser Treatments on Some Properties of the Zirconia-Porcelain Interface

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Abstract

Introduction: This study was performed to compare the effect of Fractional CO₂ laser or Q switched Nd:YAG laser of surface treatment on the shear bond strength of zirconia-porcelain interface.

Methods: Fractional CO₂ laser at 30 W, 2 ms, time interval 1 ms, distance between spots 0.3 mm, and number of scans is (4) or Q switched Nd:YAG laser at 30 J/mm² and 10 Hz were used to assess the shear bond strength of zirconia to porcelain. Pre-sintered zirconia specimens were divided into three groups (n = 10) according to the surface treatment technique used: (a) untreated (Control) group; (b) CO₂ group; (c) Nd:YAG group. All samples were then sintered and veneered with porcelain according to the manufacturer's instructions. Surface morphology was examined using a light microscope, the surface roughness test was done by the atomic force microscope (AFM), and the shear bond strength (SBS) test was done by a universal testing machine. After debonding following shear bond test, zirconia surfaces were examined under a light microscope to determine their fracture mode.

Results: The Results of this study showed that the lowest SBS was recorded in the control group, and the highest SBS recorded in the Fractional CO₂ group, followed by the Q switched Nd:YAG laser group, as well as an increase in surface roughness and change in the morphology and mode of failure in the experimental groups .

Conclusion: This study shows that Fractional CO₂ laser and Q switched Nd:YAG laser treatments significantly increase the bond strength than untreated zirconia .

Keywords: Nd:YAG laser; Fractional CO₂ laser; Shear bond strength; Zirconia; Porcelain.

Introduction

Zirconia is a highly attractive dental material compared to other dental ceramics because of its mechanical properties, such as high flexural strength (700 to 1200 MPa) and fracture toughness (7 to 10 MPa m^{1/2}), and its optical properties.¹

It is the material chosen by dentists for many dental applications and has been used as a basic material for single crowns, frameworks for fixed partial dentures, orthodontic brackets, endodontic post and implant abutments.²

Zirconia has three phases: (1) Monoclinic (m) below 1170°C, (2) Tetragonal (t) above 1170°C, and (3) Cubic (c) above 2370°C. After firing, the tetragonal-monoclinical phase transformation takes place during cooling, and the material changes from a tetragonal structure to a monoclinic, resulting in a volume increase of 3% to 5%. Some fractures and cracks can form because of the compressive-stresses in the lattice.³

Zirconia is a material with a strengthened frame, and it must be sheltered with a semi-transparent veneering porcelain to get an esthetic appearance.⁴ Effective bonding relies on

micro-mechanical interlocking between zirconia and the veneering porcelain, which is a very essential factor for the longevity of zirconia restorations.⁵ Unlike zirconia, veneering porcelain does not have good mechanical properties, and the nonexistence of strong bonding at the interface between zirconia and the veneering porcelain may result in fractures in the dental restoration.⁶

Factors affecting bond strength, including mechanical and chemical bonding, residual stress, and wettability, can affect the bonding between zirconia and porcelain.^{7,8}

Therefore, to increase the bond strengths of veneering porcelain, some surface treatment procedures on zirconia have been developed such as: the application of the liners, mechanical surface roughening, salinization, tribochemistry, thermal spray, chloro-silane treatment with steam, fusion with glassy balls, selective infiltration etching which creates intergranular porosity, corrosion with hot solutions, complex primer that reacts with hydroxyl groups and laser treatments.⁹

Previous studies have employed different lasers such as CO₂, Nd:YAG and Er:YAG for the surface treatment of zirconia and reported varying degrees of success.¹⁰ Soltaninejad et al concluded that the surface treatment

with Nd:YAG laser resulted in increased shear bond strength and surface roughness.¹¹ while Liu et al found that Nd:YAG laser cannot improve the surface roughness of zirconia.¹² Moser et al used CO₂ laser and concluded that laser treatment of zirconia increased the shear bond strength (SBS) values significantly.¹³

The aim of this study was to evaluate the effects of various laser surface-treatment (fractional CO₂ laser and Q-switched Nd:YAG laser on pre-sintered zircon) on the bond strength between the veneering ceramics and zirconia

Materials and Methods

Fabrication of Zirconia Specimens

Fifty-nine discs (9 mm diameter * 4 mm thickness) were prepared using the Y-TZP zirconia block (inCoris TZI C, Sirona, Germany). First of all, the cylinder model was designed by Pc, and then the data were exported to the CAD/CAM system (inLab CAD/CAM system, Sirona, Germany) for milling the zirconia block and producing the specimens. The bonding surface of zirconia specimens was polished using (800, 1500, 2000) grit silicon carbide abrasive paper for 15 seconds to standardized the surface roughness.¹⁴ After that, all specimens were cleaned ultrasonically using an ultrasonic cleaner with distilled water for 10 minutes to remove any contaminants. The samples were divided to form three groups:

First Group (Control Group)

Eleven pre-sintered zirconia specimens were left without laser surface treatment and sintered in a furnace (inFire HTC speed, Sirona, Germany) according to manufacturer's instructions, considered as a control group. The sample was tested by the light microscope for the assessment of surface morphology followed by the atomic force microscope (AFM) test. Ten samples were prepared for porcelain buildup according to the manufacturer instructions. These specimens were designed to test SBS testing. Each sample was attached to a piece of sticky wax (5 mm diameter * 3 mm thickness). After that, the samples were placed in a rubber mold and the investment material was poured into the mold. Then wax elimination was done using a hot steamer. Dental porcelain (VITA VM9, VITA Zahnfabrik, Germany) was applied to fill the mold after wax elimination according to the manufacturer's instructions and placed in the porcelain furnace (Programat P500, Ivoclar Vivadent, Germany).

After porcelain sintering, the investment material was removed and porcelain fused to zirconia samples was produced. All samples were soaked into a water bath filled with distilled water at 37°C for 24 hours before the SBS test.¹⁵ Each sample was attached to the universal testing machine (Instron 1195, England) and the load was applied at 1 mm/min.¹⁴ with the blade tip perpendicular to the zirconia porcelain interface. SBS was calculated

using the formula below¹⁵:

Shear bond strength (MPa) = applied force (n) / area (mm²)

SBS=n/area

Second Group (CO₂ Group)

Thirty two pre sintered zirconia specimen surfaces were irradiated with the fractional CO₂ laser 10600 nm (CO₂ Fractional laser Brouchure, JHC1180, China). To estimate the most effective laser parameters, a pilot study was conducted using a laser beam with different pulse durations (0.5, 1, 2, 3, 4, 5, 10 milliseconds) and different output powers (10, 20, 30 W) while the time interval at 0.1 ms, distance between spots 0.3 mm and number of scan 4 were fixed. After laser surface treatment, the specimens were sintered in a furnace (inFire HTC speed, Sirona, Germany) according to the manufacturer's manufacture instructions, following sintering, all samples were examined by the light microscope. To test SBS between laser treated zirconia and porcelain; a porcelain build-up and sintering was performed in the same procedure applied in the control group. Results of the pilot study including SBS test and surface morphology examination indicated that 30 W, 2 ms, 1 ms, distance between spots 0.3 mm and number of scan 4 are the best parameters showed high SBS with no microcracks. Ten samples were prepared as CO₂ group treated with these laser parameters and subjected to the SBS test after porcelain build-up. The AFM test was also performed for this group to assess the surface roughness.

Third Group (Nd:YAG Group)

Sixteen pre-sintered zirconia specimen surfaces were irradiated with the Q-SWITCHED Nd:YAG laser with a 1064-nm wavelength. The laser beam was delivered with an energy density of 15, 20, 25, 30, 35 J/cm², while the frequency was fixed to 10 Hz. Then the samples were sintered and tested by the light microscope and SBS test. Results of the pilot study indicated that 30 J/cm² and 10 Hz are the best parameters gave high SBS with no micro cracks in the tested samples. Ten samples were prepared as a Nd:YAG group and treated with these laser parameters. Porcelain build-up was performed in the same manner described in the control group and subjected to the SBS test. For this group, the AFM test was also performed.

Fracture Mode

After the SBS test, the deboned surface of the zirconia was examined microscopically with (×40) to determine the mode of fracture 15 as follows:

1. Adhesive failure: If less than 25% of the zirconia cylinder surface was covered with porcelain.
2. Cohesive failure: If less than 25% of the zirconia cylinder surface was visible.
3. Mixed failure: for all other cases.

Statistical Analysis

Descriptive statistics were computed for SBS. Statistical Methods were used in order to analyze and assess the data, including descriptive statistics (mean and standard deviation) and inferential statistics. The ANOVA test was carried out to examine the significant difference between the tested groups ($P < 0.05$). The Tukey HSD test was carried out to detect the significant differences between the two groups.

Results

Light Microscopic Observations

The photographs below show the surface morphology of the zirconia specimens (Figures 1A, B, C). The image of the untreated zirconia appears to be smoother than that of Nd:YAG and CO₂, and the surface texture of the laser-treated zirconia consists of micro-retentive pits with different degrees of roughness between the two lasers. There is no microcrack or defects appear in the microscopy images.

Shear Bond Strength

The mean SBS and standard deviations are shown in Table 1. In general, the laser surface treatment increased the SBS of zirconia to porcelain. The highest bond strength was obtained from the CO₂ group (23.6 MPa). The lowest value was obtained from the control group (7.397 MPa). The bond strength of the Nd:YAG group was lower than that of the CO₂ group (20.180 MPa).

To test the significant difference between groups, ANOVA was used. Table 2 shows a highly significant difference between the control and the experimental groups.

Table 3 shows that there is a significant difference between the control and the experimental groups, but there is a non-significant difference between the two laser treated groups.

Mode of Failure

Failure types are shown in Table 4. The analysis of the mode of failure after the SBS test revealed that the adhesive failure was the predominant mode in the control group, but the cohesive failure had the highest frequency

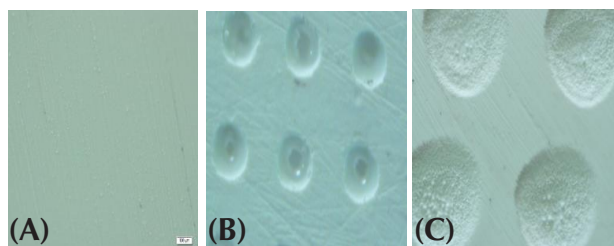


Figure 1. Light Microscopy Pictures With ($\times 100$), A. Control, B. Fractional CO₂, C. Q switched Nd:YAG.

Table 1. Mean and Standard Deviation (SD) of the SBS in the Tested Groups

Group	Mean SBS (MPa)	SD
Control	7.397	2.288
Fractional CO ₂ laser	23.603	4.007
Nd:YAG laser	20.180	5.339

Table 2. Shear Bond Strength ANOVA Test Between Groups

	Sum of Squares	df	Mean Square	F	P Value
Between groups	1459.188	2	729.594	43.959	0.00
Within groups	448.127	27	16.597		
Total	1907.315	29			

Table 3. Tukey Test Between Control and Experimental Groups

I Group	J Group	Mean Difference (I-J)	Std. Error	P Value
Control	CO ₂	-16.20600	1.82194	0.000
	Nd:YAG	-12.78300	1.82194	0.000
CO ₂	Control	16.20600	1.82194	0.000
	Nd:YAG	3.42300	1.82194	0.164
Nd:YAG	Control	12.78300	1.82194	0.000
	CO ₂	-3.42300	1.82194	0.164

Table 4. Mode of Failure Results of the Tested Groups

Mode of Failure	Control	CO ₂	Nd:YAG
Adhesive	6	1	2
cohesive	0	8	3
mixed	4	2	5

in the CO₂ groups while in the Nd:YAG group the mixed mode of failure was the highest mode

Surface Roughness Analysis

Surface roughness was evaluated by AFM. Table 5 displays surface roughness measurements of the different groups. The lowest Ra value was observed in the control specimen (12.9) followed by that

Nd:YAG laser treated group (21.6) and the highest Ra value was recorded in the with CO₂ group (28.6).

Discussion

Some studies have evaluated the bond strength between the zirconia and veneering porcelain and the surface roughness after various surface treatments on zirconia.^{17,18} Effective bonding is essential to ensure the longevity of the zirconia dental restoration; otherwise, there will be debonding of the porcelain. To remove this failure, researchers aim to improve the bond strength by increasing the surface area of zirconia through different surface-treatments.¹⁹

Moon et al applied surface treatments to pre-sintered zirconia. It was highlighted that pre-sintered surface

Table 5. Surface Roughness Measurements by the AFM Test of the Tested Group

Control	CO ₂	Nd:YAG
12.9	27.6	21.6

treatment had many benefits. It was concluded that in post-sintered zirconia laser surface treatment, micro-cracks were not occurring.²⁰ It has been reported that post-sintering surface treatments increase the fracture risk by weakening the structure of zirconia and accelerating the tetragonal to monoclinical transformation.²¹

The laser has been suggested by many authors as an alternative surface treatment method to for increasing the surface roughness of zirconia.²²⁻²⁴ Therefore, the focus of the present study was to investigate the effect of fractional CO₂ and Q switched Nd:YAG laser irradiation (at different intensities) on the bond strength of Y-TZP to porcelain prior to sintering.

Shear stresses are thought to be major stresses leading to bonding-failure of restorative materials, and the SBS tests are simple, quick and appropriate.¹¹ In this study, the SBS test was used to examine the bonding of zirconia ceramics to porcelain.

The result of this study showed that the use of the fractional CO₂ laser or the Q switched Nd:YAG laser on the surface of zirconia resulted in significantly improved SBSs compared to the control group, because of the increase of surface roughness on the zirconia surface that enhanced the interlocking with the porcelain. The effect of the laser could be related to the vaporization or ablation of the zirconia material through the photothermal process. The vaporization is considered as a micro- explosion of portions of material heated above the melting point.²⁵

This result is in agreement with that of a study by Ahrari et al who concluded that laser surface treatment on zirconia significantly increased SBS because of surface roughness.¹⁰ However, the result disagrees with Kirmali et al; they proposed that Nd:YAG lasers are not effective to in increasing the bond strength between zirconia and porcelain. This could be due to the fact that the authors in the study used different laser energy and different pulse duration.¹⁴ Alhussani and Jawad concluded that irradiation of zirconia with the fractional CO₂ laser could be mentioned as a suitable alternative methods of zirconia conventional surface treatment.²⁶

The morphology analysis in the present study showed an increase in the surface area of zirconia without any microcracks after laser irradiation. This finding disagrees with other studies. Akyıl et al and Gorler and Ozdemir reported cracks on the zirconia surface after laser treatment. This disagreement may be related to laser irradiation on fully- sintered zirconia.^{15,27}

In the study, it was observed that the number of adhesive failure types was less than that for mixed and cohesive failure types in laser treated groups because adhesive

failure is related to low bond strength.²⁸ This finding is in agreement with Cevik and colleagues study in which the adhesive mode of failure is less in the laser treated group than the control group.¹⁷ Cavalcanti et al examined the bond types after the surface treatments between ZrO₂ and resin cement and found that the adhesive failure type was higher than the mixed failure type in all groups.^{29,30} The reason may have been because surface treatments on ZrO₂ were applied after sintering

Conclusion

Within the limitations of this study, the following conclusions are drawn:

1. Both Fractional CO₂ laser and Q switched Nd:YAG laser treatments demonstrated higher bond strength than untreated zirconia and there is no significant difference in SBS between the experimental groups.
2. Laser surface treatment can change the surface roughness, surface morphology of the pre sintered zirconia and the fracture mode between zirconia and porcelain.
3. Laser parameters are a critical factor that affects the surface treatment final result.

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