ORIGINAL RESEARCH

Evaluation of Effect of Zirconia Surface Treatment with CO_2 and Nd:YAG Lasers on Shear Bond Strength between Zirconia Frameworks and Porcelain Veneers

Hadi Ranjzad[1], Bijan Heidari[2], Farzane Ostovar Rad[3], Amirreza Hendi[4], Zahra Ghorbani[5]

Abstract

Aim: The purpose of this study was to evaluate the effect of zirconia surface treatment with CO_2 and Nd:YAG laser on shear bond strength (SBS) between the zirconia framework and porcelain veneering.

Materials and methods: In this *in vitro* study, zirconia blocks were converted to 50 cubes and were divided randomly into 5 groups. After sintering (S), porcelain was applied in the control group. The surface treatment of the second to fifth groups included CO_2 laser + (S), (S + CO_2), Nd:YAG laser + (S), and (S + Nd), respectively. The SBS test was done, and data were analyzed by SPSS16 software. One sample was randomly chosen from each group and the type of failure was examined under scanning electron microscope (SEM). To compare the pairs of means, the least significant difference test was used and the determined significance level was 5% ($p < 0.05$).

Results: The SBS of S + Nd group was significantly higher than the other ones, except for S + CO_2 group. The least amount of SBS belonged to CO_2 + S and the highest to S + Nd group. There were no significant differences between the other groups.

Conclusion: The bond strength of veneering porcelain to zirconia can be altered by surface treatments. It can also be affected by the type and sequence of laser and sintering application. The effect of Nd:YAG laser on the surface of zirconia, in order to create roughness to increase SBS, is better than that of CO_2 laser.

Clinical significance: Surface treatment of zirconia by certain types of lasers reduces the chipping of the ceramic veneer and increases the success rate of all-ceramic restorations.

Keywords: CO_2 laser, Nd:YAG laser, Shear bond strength, Sintering, Zirconia.

The Journal of Contemporary Dental Practice (2022): 10.5005/jp-journals-10024-3412

Introduction

Esthetics play an important role in patients' satisfaction in the field of dentistry, and apart from tissue adaptation, nonmetallic ceramic restorations provide a much better appearance than their metal–ceramic counterparts. Thus, there is still an on-going search for an ideal all-ceramic restoration, and in the meanwhile, following features are looked for: the physical characteristics, strength, edge synchronization, and a perfect appearance for the anterior and posterior teeth. In many cases, all-ceramic prosthesis can potentially create a more pleasant look than a metal–ceramic restoration. In the latter, the metal infrastructure creates an opaque appearance, and the metal margins are usually observable. Its other drawbacks include risk for a metal allergy, breaking of the bond, and porcelain's color change. Reinforced all-ceramic prosthesis include a high-strength core (such as zirconia), which is covered by porcelain.[1–3]

Zirconia is a crystalline oxide of zirconium, and its mechanical properties are quite similar to the metals and its color to that of the teeth. In 1975, Garvie showed that it has great mechanical characteristics and called it steel ceramic.[4] Nowadays, zirconium has been mixed with computer-aided design (CAD)/computer-aided manufacturing (CAM) computer systems and has made a revolution in dentistry. For making a zirconia core, it is necessary to use a proper CAD/CAM system, which can work on zirconia. In comparison with other all-ceramic restorations, their frameworks are the most reliable.[5] Having said that, their weakest point is chipping or cracking of the veneer. Zirconia restorations also have the mechanical properties for being used in the posterior areas of the mouth.[6] For reaching a strong bonding, the mechanical properties of the core and porcelain veneer must be adaptable with each other. Having a strong bonding is necessary for making sure of the structural unity of the restoration under functional forces, and also for avoiding delamination and chipping of the veneer.[2] It has been reported that all-ceramic restorations, which had the

[1,4]Department of Prosthodontics, Dental Sciences Research Center, School of Dentistry, Guilan University of Medical Sciences, Rasht, Iran

[2]Prosthodontist, Private Office

[3]Department of Maxillofacial Radiology, Dental Sciences Research Center, School of Dentistry, Guilan University of Medical Sciences, Rasht, Iran

[5]Department of Prosthodontics, Dental Sciences Research Center, School of Dentistry, Guilan University of Medical Sciences, Rasht, Iran

Corresponding Author: Zahra Ghorbani, Department of Prosthodontics, Dental Sciences Research Center, School of Dentistry, Guilan University of Medical Sciences, Rasht, Iran, Phone: +0098 9120248577, +0098 1332119328; e-mail: z.ghorbani.18@gmail.com

How to cite this article: Ranjzad H, Heidari B, Rad FO, *et al*. Evaluation of Effect of Zirconia Surface Treatment with CO_2 and Nd:YAG Lasers on Shear Bond Strength between Zirconia Frameworks and Porcelain Veneers. J Contemp Dent Pract 2022;23(10):1026–1032.

Source of support: Nil

Conflict of interest: None

veneer ceramic attached to zirconia frame, showed a 13% chipping of the ceramic in 3 years and 15.2% in 5 years while breaking of metal–ceramics were 8–10% in 10 years. As a result, for increasing their long-term clinical success rate, it is important to increase the bonding strength between ceramic veneer and frameworks in zirconia restorations. Stress distribution in a two-phase structure is more complicated than a single-phase one, and since the interface of core and veneer is one of the weakest areas in veneer restorations, thus more factors must be considered in layered restorations.[2] Bonding mechanism includes chemical bonding, mechanical adaptation, and pressure stress due to difference in heat expansion coefficient between tetragonal zirconia polycrystal and ceramic veneer. However, it must be mentioned that the exact bonding mechanism between zirconia and ceramic veneer has not been fully understood yet. The strength of the mentioned bonding is affected by many factors;[7,8] most important of which are surface finishing in core, chemical bonding strength, mechanical interlocking, type and rate of interface deficiencies, the use of porcelain liner, and wetting features along with pressure stress rate in veneer layer due to difference in heat expansion rate between zirconia and porcelain veneer.

Various methods have been introduced for improving the bond between porcelain veneer and zirconia, some of which are sandblasting, silica coating, liner, abrasion by diamond drills, and thermal preparation of zirconia's surface.[9–12] The methods that cause roughness in zirconia surface can have devastating effects on its mechanical characteristics, such as flexural strength and durability.[13,14]

Due to lack of silica and glass phase in zirconia ceramics, performing acid etching for creating a rough surface by using HF acid does not make a meaningful difference for improving the bond strength.[15] Air abrasion is usually used for creating a rough topography on the surface of zirconia framework in order to increase the contact surface for bond and for increasing the surface energy and also wetting characteristics.[16,17] But it must be mentioned that this method leaves tracks and other deficiencies in zirconia that would be the starting point of broken frames and thus endangering its mechanical features and longevity.[18]

Recently, easy-to-use and efficient surface treatment methods have been proposed using laser radiation. The laser beams that are used in dentistry depending on the wavelength, power, and the type of target tissue can either make stimulus, rupture or extracting.[19] Although Maiman used the ruby laser on an extracted tooth for the first time in 1960, its actual use in dentistry started many years later.[20] The use of high-strength laser started in 1989 with pulsed Nd:YAG by Terry Myers.[21] From 1990 onward, the lasers used in surgery, with little modifications, were used in dentistry as well; examples of which include argon, CO_2, Nd:YAG, and Erbium. Recently, certain types of lasers, namely, CO_2, Nd:YAG, and Er:YAG have been used for creating surface roughness in ceramics zirconia.[17,22,23] Using radiation of CO_2 laser is an ideal preparation method for porcelain materials since its beams are almost completely absorbed by the porcelain due to its specific wavelength.

Previous studies have employed different lasers such as CO_2, Nd;YAG, and Er;YAG for the surface treatment of zirconia and reported varying degrees of success.[24,25] So, this study was done to assess the effects of using Nd:YAG and CO_2 lasers and also the role of heat treatment of zirconia's surface for the bond between zirconia and ceramic veneer.

Materials and Methods

Study Design

This *in vitro* research was carried out in the Dental Sciences Research Center and the Department of Prosthodontics, Tehran, Iran.

Sample Size Calculation

In this *in vitro* research, first, by using a diamond disk, zirconia blocks (YZ Cubes, Vita Zahnfabrik, badsäckingen, Germany) were cut into 50 square cubes, which measured 13.5 millimeters at each side. Those 50 cubes were randomly divided into 5 equal groups ($n = 10$). In each group, other than the 10 original cubes, 1 extra sample was added for evaluation under the electron microscope.

Preparation of Zirconia Samples

At the first step, the surface of all zirconia samples was polished under water using a silicon carbide-coated abrasive paper with a grit size of 1200 (Struers A/S, Rodovre, Denmark), and then they were cleaned using 70% ethanol alcohol and distilled water in the ultrasonic machine for 5 minutes.

Study Groups

The samples of the first group (C = control), which did not receive any surface treatment (traditional method) underwent sintering for 2 hours in a furnace at 1510 °C, based on the manufacturer's instructions. Due to a 20% shrinkage of zirconia, all the 55 samples shrank to square cubes with dimensions of 10 mm on each side. For having an even layer of porcelain on the sintered blocks, an index made of condensation silicone with a consistent Putty (Spidex, Coltene AG, Altstatten, Switzerland) was made and placed 2 mm higher than the edge of the sintered block of zirconia. And while the porcelain was being made, the zirconia block was placed inside the index and VM9 dentin porcelain with coloring code 2 M2 (Vita, Bad Säckingen, Germany) was added up to the edge of the index. Based on the manufacturing guideline, after adding the porcelain to the first group (C), it was baked in the furnace. In order to recreate the clinical conditions and for fixing the shortcomings of the first bake (bisque stage), all samples underwent a second baking. Based on the type of the laser, sequence of laser procedures, and sintering, the rest of the samples were divided as following: in the second group, first, laser was radiated on the surface of the samples using CO_2 (Smart US 20D, Deka, Florence, Italy) and afterward, they underwent sintering (CO_2 + S). Similarly, CO_2 and sintering were used in the third group, only reversing the sequence (S + CO_2). In the fourth group, scanning of the surface was done using Nd:YAG laser (Fidelis, Fotona, Slovenia) and after that they underwent sintering (Nd + S). The same laser was used in the fifth group, and, here again, the only difference was the sequence of the procedure (S + Nd).

Laser and Sintering Procedure

With a distance of 1 cm to the sample's surface, CO_2 laser was radiated with a power of 3 watts and in the form of a continuous wave and according to the manufacturer's guidelines. The Nd:YAG laser in the research had a power of 2 watts and energy of 100 mj per pulse, in the form of LP (320 microseconds) with a frequency of 10 Hz and with a distance of 1 mm from the surface of the samples. The scanning speed for all four groups were 2 mm per second. The beam diameter in CO_2 was 0.5 mm, and 0.3 mm in Nd:YAG. Based on the scanning speed and also the area of the samples before and after sintering, the timing for the second (CO + S) and fourth group (Nd + S) was 60 seconds, and the third (S + CO) and fifth group (S +

Nd) was 45 seconds. After the application of the laser in the second and fourth groups, the sintering was performed in the furnace for 2 hours at 1510°C.

One extra sample, before application of porcelain veneer, was randomly chosen from each group in order to be analyzed under the electronic microscope (TESCAN, USA) for the effects of sintering and laser. Due to gold coating of the samples, the SBS test was not performed on them.

Finally, the adding of the porcelain for the fourth group was done similar to the control group.

Shear Bond Strength Test

Samples had to be mounted in the jig for performing the SBS test. For keeping the samples completely in place, during applying the force, and before the bond failure, they were tightly encased by three screws. The samples were put in their proper place in the universal testing machine (Zwick, Ulm, Germany, 2010), and the vertical arm of the chisel was set in a way that the force would precisely be applied to the veneer's core interface. In the next stage, the vertical arm, along with the attached chisel, started to do the forcing. The head speedcross was 0.5 mm per minute and it continued to the failure point. The applied force (in Newton) was measured and recorded and was changed into SBS based on the following formula:

$$\text{SBS (MPa)} = \textit{Load}\ (N)/\textit{Area}\ (\text{mm}^2)$$

In the analysis of the sample failure, after testing SBS one sample was randomly chosen from each group and the type of failure was analyzed under an SEM microscope.

Statistical Analysis

The obtained data were subjected to statistical analysis using statistical package for social sciences (SPSS) software, version 20. Data presented as mean, standard deviation, standard error, minimum, and maximum when appropriate. The variance analysis was used to compare the means between tested groups while the LSD method was used for pairwise comparison of means. The significance level was set at $p < 0.05$

Results

Based on the findings in Table 1, the SBS of zirconia for study groups including (C), (CO + S), (S + CO), (Nd + S), and (S + Nd) were 49.8, 47.3, 65.7, 49.7, and 70.8 MPa, respectively.

The results of Table 2 showed a significant difference between the preparation methods (p-value = 0.039) based on the variance analysis. Due to significant difference of SBS between zirconia and porcelain layer in different methods, the follow-up tests were performed by multiple comparisons using the LSD.

Based on the results of Table 3, intergroup comparison showed a significant difference between the SBS using Nd:YAG after sintering with the control group at the meaningful level of 5% (p-value = 0.027). Also, there was a significant difference between the SBS using CO_2 laser before sintering with Nd:YAG and after sintering at the meaningful level of 5% (p-value = 0.014). The SBS using Nd:YAG before sintering in comparison with Nd:YAG after sintering was at the meaningful level of 5% (p-value = 0.026). The SBS of S + Nd group was significantly more than other groups except S + CO_2. The lowest amount of SBS belonged to CO_2 + S and the highest was to S + Nd group. There were no significant differences between other groups.

Regarding Figures 1 to 3, the images were obtained through an SEM, after surface treatment, and before application of porcelain, and finally, photos of post-failure of the samples are shown as well.

Discussion

One of the weak points of using zirconia in restorations is the interface between core and veneer. Since the natural strength of porcelain veneer is less than core and this can cause the failure points in all-ceramic restorations, so a strong bond between ceramic veneer and framework is necessary for making sure of the structural unity of the restoration under functional forces, and also

Table 1: The descriptive data on the SBS of zirconia

Group	*Number*	*Mean*	*Standard deviation*	*Standard error*	*Minimum*	*Maximum*
Control	10	49.80	23.799	7.526	19	89
CO_2 laser before sintering	10	47.30	18.276	5.779	10	72
CO_2 laser after sintering	10	65.70	11.586	3.664	44	82
Nd:YAG laser before sintering	10	49.70	14.229	4.500	27	73
Nd:YAG laser after sintering	10	70.80	29.389	9.294	32	117
Total	50	56.66	21.925	3.101	10	117

Table 2: Variance analysis results

Source of variance	*Mean squared errors*	*Degrees of freedom*	*Mean squares*	*F-statistics*	*p-value*
Intergroup (preparation methods)	4647.720	4	1161.930	2.765	0.039
Intragroup	18907.500	45	420.167		
Total	23555.220	49			

Table 3: The results of multiple comparisons in the form of LSD

I-group	*J-group*	*Mean difference*	*p-value*
Control	CO_2 laser before sintering	2.500	0.786
	CO_2 laser after sintering	−15.900	0.090
	Nd:YAG laser before sintering	0.100	0.991
	Nd:YAG laser after sintering	−21.000	0.027*
CO_2 laser before sintering	CO_2 laser after sintering	−18.400	0.051
	Nd:YAG laser before sintering	−2.400	0.795
	Nd:YAG laser after sintering	−23.500	0.014*
CO_2 laser after sintering	Nd:YAG laser before sintering	16.0	0.088
	Nd:YAG laser after sintering	−5.100	0.581
Nd:YAG laser before sintering	Nd:YAG laser after sintering	−21.100	0.026*

*The level of meaningfulness: 5%.

for avoiding delamination and chipping of the veneer.[26] This *in vitro* study was done to evaluate the effect of zirconia surface treatment with different lasers. The SBS test was evaluated for the control group (only sintering) and other groups including (CO_2 + S), (S + CO_2), (Nd + S), and (S + N). The result of the SBS test was analyzed by SPSS16 software. The variance analysis and LSD method were used to compare the means between tested groups and pairwise comparison of means, respectively.

The SBS is the most appropriate examination for porcelain bonds.[27] Since the shear stress is the most common type of stress responsible for breaking of the bonding in clinical conditions and SBS is easily and quickly deployable, this was the test of choice in this study as well.[28] The important point about stabilizing the samples was a precise parallelism of interface with the surface of mold since any sloping of the mounted sample's interface, while applying the force, would result in an incorrect measurement of the SBS. For doing so, a different coloring than zirconia core was used for porcelain veneers in the treatment stage so that the prepared surface would be aligned with the jig and parallel to chisel while its sharp edge in the interface would be perpendicular to the horizon.

Based on the results, a significant difference was between the SBS using Nd:YAG after sintering with control group (*p*-value = 0.027). Also, there was a similar difference between the SBS using CO_2 laser before sintering with Nd:YAG and after sintering (*p*-value = 0.014). The SBS using Nd:YAG before sintering in comparison with Nd:YAG after sintering was at the meaningful level of 5% (*p*-value = 0.026). The effect of Nd:YAG laser on the surface of zirconia in order to create roughness to increase SBS was better than CO_2 laser. Thus, the result of this study showed that the type and sequence of laser and sintering application can affect the bond strength of veneering porcelain to zirconia. Similar to this study, there are several other studies that have examined the SBS of several materials and their compatible veneer has been analyzed.[29–32]

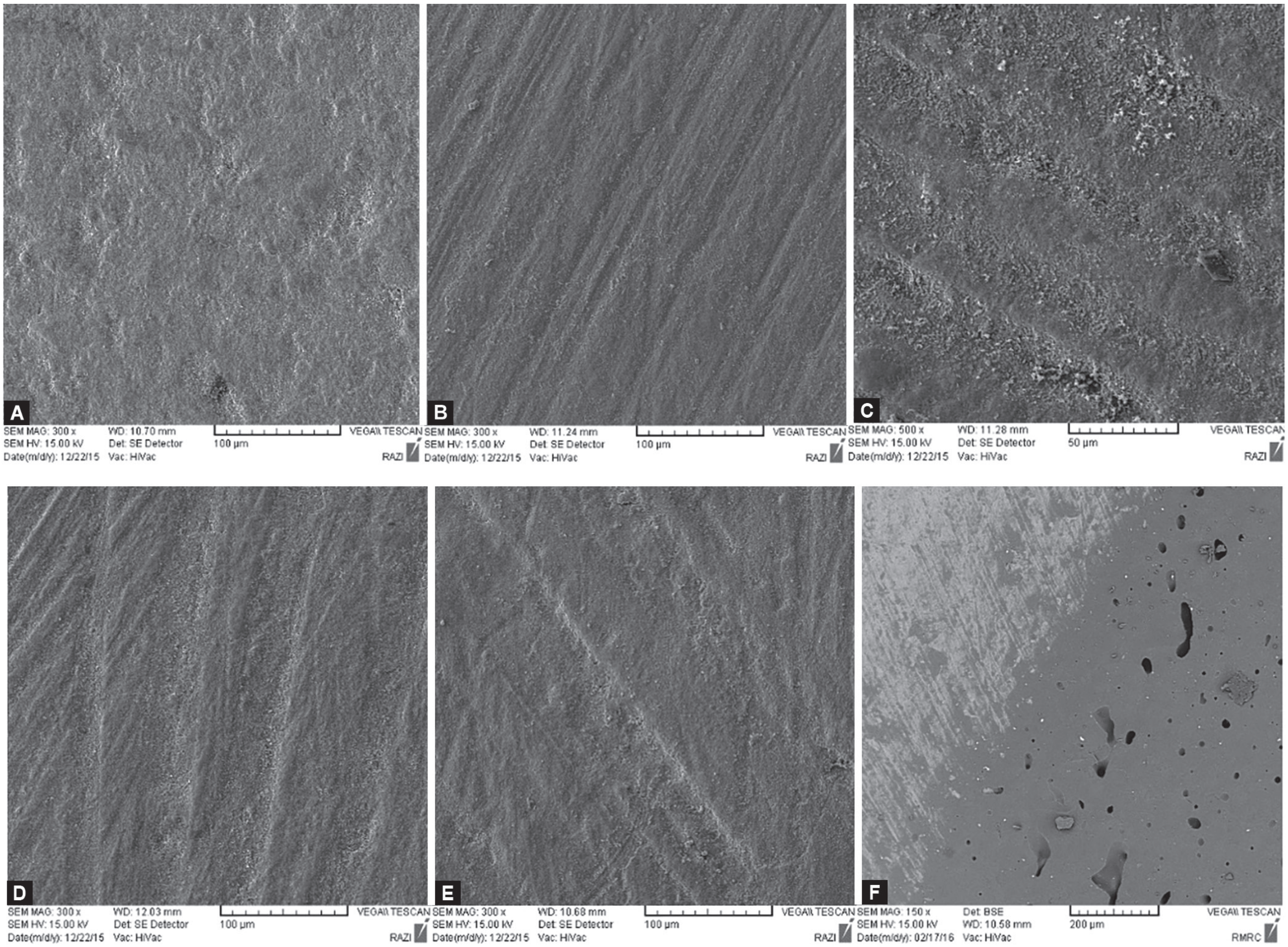
In this study, the SBS had their lowest figures in CO_2 + S (47.25 MPa) and their highest in S + Nd (70.30 MPa). The differences were not statistically significant except for S + Nd, which showed a significant difference with the control group. The reason for a low number in CO_2 + S, compared to others, could be due to the application of laser on zirconia samples at first and performing the sintering afterward. As shown in SEM pictures (Fig. 1A), CO_2 laser's penetration in zirconia surface was excessive and created a groovy look.[33] If laser creates deep grooves, it can damage zirconia frame in fixed prostheses since the depth of their frames are 0.3–1 mm.[33]

Primary studies that used the SBS test reported a range of the SBS between 9.4[34] and 31 mega pascal[35] between Y-TZP and ceramic veneer. In the current study, the figures are higher and the reason for such difference was believed to be due to the lack of any standard for sample preparation, study conditions, and analyzing methods. On the other hand, some researchers believe that the shear test results are greatly affected by the shapes and designs of the samples, and this makes comparing the results of various studies complicated.[36]

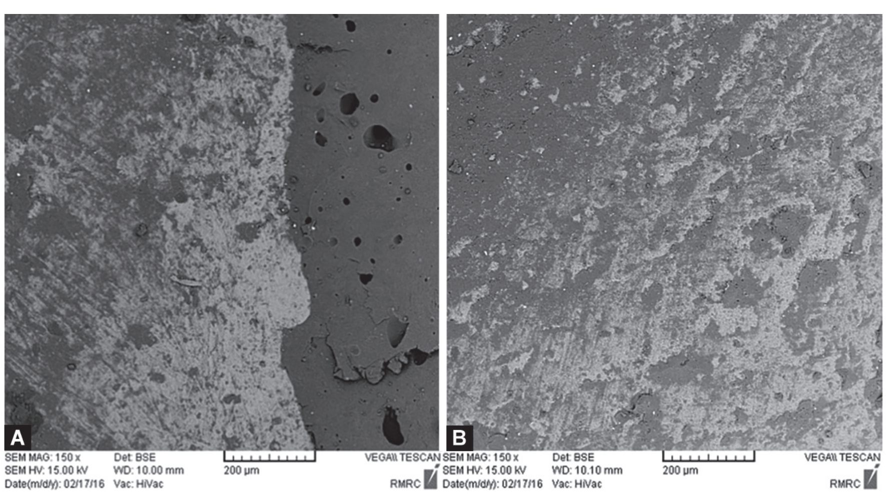
The results of this research is in agreement with other studies and they showed that CO_2, compared to other surface treatment methods such as sandblasting, Er:YAG laser, and Nd:YAG laser, was not effective for increasing the SBS and even reduced it.[37,38] In CO_2 + S group, since sintering is performed after CO_2 procedure, it can be conceived that sintering would decrease the roughness in zirconia surface because of phase transformation of zirconia and as a result affects the SBS. SEM pictures are a confirmation to this notion.

In S + Nd group, first, the sintering was done. The sintered zirconia would probably resist better toward the undesirable changes of laser and minute explosion happening at the time of laser procedure. Those explosions leave debris behind which can attach to the melted surface of the ceramic and thus unbalance the bond.[39] Also, sintering increases the t-phase in zirconia, and the heat expansion coefficient between zirconia framework and porcelain veneer causes the strengthening of the bond.[40] Thus, laser procedures should be done after sintering. The pictures of SEM after the failure mode approve the point that the SBS in S + Nd had been the highest since the SEM picture of the random sample shows the failure to be completely cohesive in porcelain layer (Fig. 3A) while in other groups a range of failures was seen. In the microscopic pictures after the failure, backscatter mode was used for a better diagnosis and analysis of the layers which caused an easier differentiation between zirconia and porcelain.

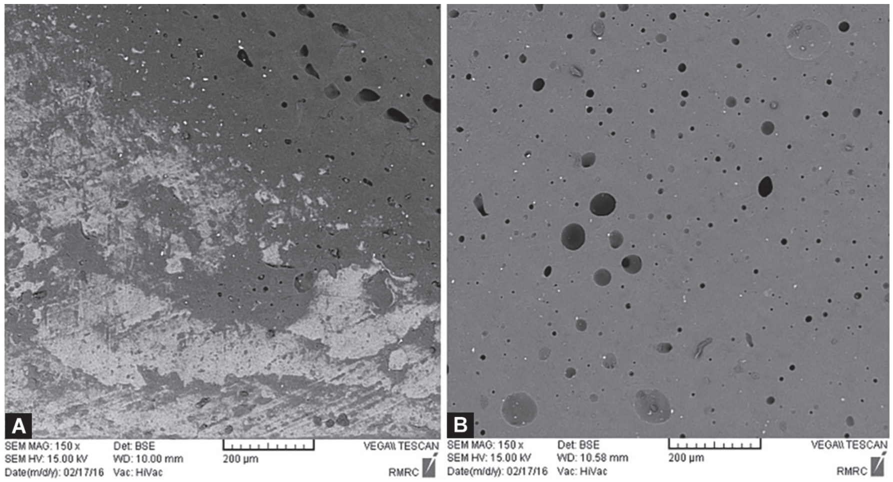
Under the conditions of performing laser after sintering, the CO_2 laser group showed a lower SBS compared to Nd:YAG (Table 1). The rate and pattern of the surface roughness created by Nd:YAG explain this difference. SEM pictures showed that the tracks caused by CO_2 were wider compared to Nd:YAG. The probable cause of the



Figs 1A to F: (A) The picture of an SEM after surface treatment of first group (group C). (B) The picture of an SEM after surface treatment of the second group, with deep tracks (group CO + S). (C) The picture of SEM after surface treatment of the third group (group S + CO). (D) The picture of SEM after surface treatment of the fourth group (group Nd + S). (E) The picture of SEM after surface treatment of the fifth group, with even and regular porosity (group S + Nd). (F) The picture of backscatter after mixed failure (group C)



Figs 2A and B: (A) The picture of backscatter after mixed failure (group CO + S). (B) The picture of backscatter after mixed failure (group S + CO)



Figs 3A and B: (A) The picture of backscatter after mixed failure (group Nd + S). (B) The picture of backscatter after cohesive failure (group S + Nd)

tracks can be attributed to higher energy of CO_2 laser and making a higher temperature and a subsequent cooling stress.[38,41] Moreover, CO_2 laser beam has a bigger diameter compared to Nd:YAG (0.5 mm vs 320 micron), which can transfer more energy and damage the surface layer more.[38] The present study shows similar results to those reporting a higher bond strength for Nd:YAG compared to air-borne and silica coating.[42,43]

Similar to the results of the present study, Paranhos et al.[38] and Henriques et al.[44] reported Nd:YAG laser to be meaningfully effective on the SBS, and compared to CO_2 laser, significantly increased the bond strength (14 vs 7.9 MPa).

Da Silveira et al. and Spohr et al.[42,43] also reported results similar to the study at hand. Those two studies had laser settings similar to the present study but used graphite powder for increasing laser energy absorption since alumina-based ceramics do not absorb the 1064 nm frequency emitted by Nd:YAG laser. Zirconia ceramic can absorb the laser energy and does not need any initiators, such as graphite.

Akyil et al.[17] announced that Nd:YAG and ER:YAG lasers had increased the irregularities on the zirconia surface. In contrast with the current results, they showed that Nd:YAG laser had decreased the SBS compared to control group.

Kasraei et al.[45] showed that surface treatment by CO_2 laser makes a stronger bond compared to Er:YAG laser and the reason can be attributed to the amount and type of created surface irregularities on the zirconia surface.

In accordance with this research, Bitencourt et al.[46] reported that the laser treatment is capable of improving the roughness of the zirconia surface and, consequently, the bond strength with resin cement and veneering ceramics. Er:YAG laser, however, did not present a favorable tendency toward bond strength, which was not investigated in the present research

Conclusion

With the limitations of this study in mind, following points can be concluded: Surface treatment can affect the strength of porcelain veneer bond to zirconia; also, the type of laser, the sequence of laser procedures, and the temperature can affect the bond strength. Moreover, for creating surface roughness in order to increase the SBS, Nd:YAG laser on zirconia surface acts more effectively than CO_2. Thus, for increasing the mentioned strength, using laser after sintering is recommended.

Limitations and Suggestions

Restrictions in the use of thermocycling and cyclic loading lead to a lack of full-scale simulation of the examined samples compared to the clinical conditions. In future studies, the samples should be examined under of thermocycling and cyclic loading to reconstruct the conditions of the mouth.

References

1. Toksavul S, Türkün M, Toman M. Esthetic enhancement of ceramic crowns with zirconia dowels and cores: A clinical report. J Prosthet Dent 2004;92(2):116–119. DOI: 10.1016/j.prosdent.2004.03.032.
2. Aboushelib MN, Kleverlaan CJ, Feilzer AJ. Microtensile bond strength of different components of core veneered all-ceramic restorations. Part 3: double veneer technique. J Prosthodont 2008;17(1):9–13. DOI: 10.1111/j.1532-849X.2007.00244.x.
3. López Mollá MV, Martínez González A, Mañes Ferrer JF, et al. Bond strength evaluation of the veneering-ceramics bonds. Med Oral Patol Oral Cir Bucal 2010;15(6):e919–923. PMID:20383103.
4. Conrad HJ, Seong W-J, Pesun IJ. Current ceramic materials and systems with clinical recommendations: a systematic review. J prosthet dent 2007;98(5):389–404. DOI: 10.1016/S0022-3913(07)60124-3.
5. Kohal RJ, Klaus G, Strub JR. Zirconia-implant-supported all-ceramic crowns withstand long-term load: A pilot investigation. Clin Oral Implants Res 2006;17(5):565–571. DOI: 10.1111/j.1600-0501.2006.01252.x.
6. Manicone PF, Iommetti PR, Raffaelli L. An overview of zirconia ceramics: Basic properties and clinical applications. J Dent 2007;35(11):819–826. DOI: 10.1016/j.jdent.2007.07.008.
7. Al-Shehri SA, Mohammed H, Wilson CA. Influence of lamination on the flexural strength of a dental castable glass ceramic. J Prosthet Dent 1996;76(1):23–28. DOI: 10.1016/s0022-3913(96)90341-8.
8. De Jager N, Pallav P, Feilzer AJ. The influence of design parameters on the FEA-determined stress distribution in CAD–CAM produced all-ceramic dental crowns. Dent Mater 2005;21(3):242–251. DOI: 10.1016/j.dental.2004.03.013.

9. Creugers NH, Käyser AF, van't Hof MA. A meta-analysis of durability data on conventional fixed bridges. Community Dent Oral Epidemiol 1994;22(6):448–452. DOI: 10.1111/j.1600-0528.1994.tb00795.x.
10. Scurria MS, Bader JD, Shugars DA. Meta-analysis of fixed partial denture survival: Prostheses and abutments. J Prosthet Dent 1998;79(4):459–464. DOI: 10.1016/s0022-3913(98)70162-3.
11. Sailer I, Feher A, Filser F, et al. Prospective clinical study of zirconia posterior fixed partial dentures: 3-year follow-up. Quintessence Int 2006;37(9):685693. PMID:1701763.
12. Fischer J, Grohmann P, Stawarczyk B. Effect of zirconia surface treatments on the shear strength of zirconia/veneering ceramic composites. Dental Mater J 2008;27(3):448–454. DOI: 10.4012/dmj.27.448.
13. Guazzato M, Quach L, Albakry M, et al. Influence of surface and heat treatments on the flexural strength of Y-TZP dental ceramic. J Dentist 2005;33(1):9–18. DOI: 10.1016/j.jdent.2004.07.001.
14. Kumbuloglu O, Lassila LV, User A, et al. Bonding of resin composite luting cements to zirconium oxide by two air-particle abrasion methods. Oper Dent 2006;31(2):248–255. DOI: 10.2341/05-22.
15. Bona AD, Borba M, Benetti P, et al. Effect of surface treatments on the bond strength of a zirconia-reinforced ceramic to composite resin. Braz Oral Res 2007;21(1):10–15. DOI: 10.1590/s1806-83242007000100002.
16. Bottino MA, Valandro LF, Scotti R, et al. Effect of surface treatments on the resin bond to zirconium-based ceramic. Int J Prosthodont 2005;18(1):6065. PMID:15754894.
17. Akyıl MŞ, Uzun İH, Bayındır F. Bond strength of resin cement to yttrium-stabilized tetragonal zirconia ceramic treated with air abrasion, silica coating, and laser irradiation. Photomed Laser Surg 2010;28(6):801–818. DOI: 10.1089/pho.2009.2697.
18. Piascik J, Swift E, Thompson J, et al. Surface modification for enhanced silanation of zirconia ceramics. Dent Mater 2009;25(9):1116–1121. DOI: 10.1016/j.dental.2009.03.008.
19. Yaghmaeian-Mahabadi M, Majdabadi A, Fekrazad R, et al. Evaluating the interaction of 308-nm xenon chloride excimer laser with human dentin and enamel hard tissues. Feyz Journal of Kashan University of Medical Sciences. 2017;21(5):460–469. DOI: 10.17795/DCEJ-5527.
20. Maiman TH. Addendum 10: Reprint of TH Maiman,"Stimulated Optical Radiation in Ruby," Nature, 187, 493–494 (August 6, 1960). The Laser Inventor: Springer; 2018. p. 299–301.
21. Myers T, Myers W, Stone R. First soft tissue study utilizing a pulsed Nd: YAG dental laser. Northwest Dent 1989;68(2):14–17. PMID:2622793.
22. Ural Ç, Külünk T, Külünk Ş, et al. The effect of laser treatment on bonding between zirconia ceramic surface and resin cement. Acta Odontol Scand 2010;68(6):354–359. DOI: 10.3109/00016357.2010.514720.
23. Casucci A, Mazzitelli C, Monticelli F, et al. Morphological analysis of three zirconium oxide ceramics: Effect of surface treatments. Dental Mater. 2010;26(8):751–760. DOI: 10.1016/j.dental.2010.03.020.
24. Liu L, Liu S, Song X, et al. Effect of Nd: YAG laser irradiation on surface properties and bond strength of zirconia ceramics. Lasers Med Sci 2015;30(2):627–634. DOI: 10.1007/s10103-013-1381-7.
25. Ahrari F, Boruziniat A, Mohammadipour HS, et al. The effect of surface treatment with a fractional carbon dioxide laser on shear bond strength of resin cement to a lithium disilicate-based ceramic. Dent Res J 2017;14(3):195–202. DOI: 10.4103/1735-3327.208762.
26. Pjetursson BE, Tan K, Lang NP, et al. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years: I. Implant-supported FPDs. Clin Oral Implants Res 2004;15(6):625–642. DOI: 10.1111/j.1600-0501.2004.01117.x.
27. Al-Dohan HM, Yaman P, Dennison JB, et al. Shear strength of core-veneer interface in bi-layered ceramics. J Prosthet Dent 2004;91(4):349–355. DOI: 10.1016/j.prosdent.2004.02.009.
28. De Backer H, Van Maele G, De Moor N, et al. An 18-year retrospective survival study of full crowns with or without posts. Int J Prosthodont 2006;19(2):136–142. DOI: 10.1007/s11126-017-9535-6.
29. Aboushelib MN, de Kler M, van der Zel JM, et al. Effect of veneering method on the fracture and bond strength of bilayered zirconia restorations. Int J Prosthodont 2008;21(3):237–240. PMID:18548963.
30. Özkurt Z, Kazazoglu E, Ünal A. In vitro evaluation of shear bond strength of veneering ceramics to zirconia. Dent Mater J 2010;29(2):138–146. PMID:20379023.
31. Saito A, Komine F, Blatz MB, et al. A comparison of bond strength of layered veneering porcelains to zirconia and metal. J Prosthet Dent 2010;104(4):247–257. DOI: 10.1016/S0022-3913(10)60133-3.
32. Vidotti HA, Pereira JR, Insaurralde E, et al. Thermo and mechanical cycling and veneering method do not influence Y-TZP core/veneer interface bond strength. J Dent 2013;41(4):307–312. DOI: 10.1016/j.jdent.2012.12.001.
33. Maruo Y, Nishigawa G, Irie M, et al. Effects of irradiation with a CO_2 laser on surface structure and bonding of a zirconia ceramic to dental resin cement. J Lasers Micro/Nanoeng 2011;6(2):174–179. DOI: 10.2961/jlmn.2011.02.0014.
34. Guess PC, Kuliš A, Witkowski S, et al. Shear bond strengths between different zirconia cores and veneering ceramics and their susceptibility to thermocycling. Dent Mater 2008;24(11):1556–1567. DOI: 10.1016/j.dental.2008.03.028.
35. Fischer J, Stawarzcyk B, Trottmann A, et al. Impact of thermal misfit on shear strength of veneering ceramic/zirconia composites. Dental Mater 2009;25(4):419–423. DOI: 10.1016/j.dental.2008.09.003.
36. Anusavice K, Kakar K, Ferree N. Which mechanical and physical testing methods are relevant for predicting the clinical performance of ceramic-based dental prostheses? Clin Oral Implants Res 2007;18:218–231. DOI: 10.1111/j.1600-0501.2007.01460.x.
37. Akın H, Ozkurt Z, Kırmalı O, et al. Shear bond strength of resin cement to zirconia ceramic after aluminum oxide sandblasting and various laser treatments. Photomed Laser Surg 2011;29(12):797–802. DOI: 10.1089/pho.2011.3039.
38. Paranhos MPG, Burnett Jr LH, Magne P. Effect of Nd: YAG laser and CO_2 laser treatment on the resin bond strength to zirconia ceramic. Quintessence Int 2011;42(1):79–89. PMID:21206937.
39. Subaşı MG, İnan Ö. Evaluation of the topographical surface changes and roughness of zirconia after different surface treatments. Lasers Med Sci 2012;27(4):735–742. DOI: 10.1007/s10103-011-0965-3.
40. Fischer J, Stawarczyk B. Compatibility of machined Ce-TZP/Al2O3 nanocomposite and a veneering ceramic. Dental Mater 2007;23(12):1500–1505. DOI: 10.1016/j.dental.2007.01.005.
41. Abdulsatar AM, Hussein BM, Mahmood AM. Effects of different laser treatments on some properties of the zirconia-porcelain interface. J Lasers Med Sci 2021;12:e2. DOI: 10.34172/jlms.2021.02.
42. Da Silveira BL, Paglia A, Burnett Jr LH, et al. Micro-tensile bond strength between a resin cement and an aluminous ceramic treated with Nd: YAG laser, Rocatec System, or aluminum oxide sandblasting. Photomed Laser Surg 2005;23(6):543–548. DOI: 10.1089/pho.2005.23.543.
43. Spohr AM, Borges GA, Júnior LHB, et al. Surface modification of In-Ceram Zirconia ceramic by Nd: YAG laser, Rocatec system, or aluminum oxide sandblasting and its bond strength to a resin cement. Photomed Laser Surg 2008;26(3):203–238. DOI: 10.1089/pho.2007.2130.
44. Henriques B, Fabris D, Souza JC, et al. Bond strength enhancement of zirconia-porcelain interfaces via Nd: YAG laser surface structuring. J Mech Behav Biomed Mater 2018;81:161–167. DOI: 10.1016/j.jmbbm.2018.02.031.
45. Kasraei S, Rezaei-Soufi L, Heidari B, et al. Bond strength of resin cement to CO_2 and Er: YAG laser-treated zirconia ceramic. Restor Dent Endodontics 2014;39(4):296–302. DOI: 10.5395/rde.2014.39.4.296.
46. Bitencourt SB, Ferreira LC, Mazza LC, et al Effect of laser irradiation on bond strength between zirconia and resin cement or veneer ceramic: A systematic review and meta-analysis. J Indian Prosthodont Soc 2021;21(2):125. DOI: 10.4103/jips.jips_590_20.