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Bond Strength of Resin Cement and Glass Ionomer to Nd:YAG Laser-Treated Zirconia Ceramics

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Abstract

Purpose: To investigate the effect of neodymium-doped yttrium aluminum garnet (Nd:YAG) laser irradiation on the surface properties and bond strength of zirconia ceramics.

Materials and Methods: Forty-eight zirconia ceramic pieces ($4 \times 4 \times 1$ mm^3) were divided into four groups according to surface treatment as follows: two control groups (no treatment) for resin bonding (CRC) and glass ionomer (GI) bonding (CGC); two laser treatment groups (Nd:YAG irradiation, 3 W, 200 MJ, 10 Hz, 180 μs) for resin bonding (LRC) and GI bonding (LGC). The ceramics in the control groups and the laser groups were distinguished by the application of different cements (resin cement and GI). Following surface treatments, the specimens were cemented to human dentin with resin cement and GI. After bonding, the shear bond strength (SBS) of the ceramic to dentin was measured, and the failure mode of each specimen was analyzed using a stereomicroscope. A one-way ANOVA compared the average bond strength of the four groups. Pairwise comparisons among the groups were performed using the Games-Howell test. The level of significance was set at 0.05.

Results: The means ($\pm$ standard deviation) of SBS values in the CRC, CGC, LRC, and LGC groups were 3.98 ± 1.10, 1.66 ± 0.59, 10.24 ± 2.46, and 2.21 ± 0.38 MPa, respectively. Data showed that the application of the Nd:YAG laser resulted in a significantly greater SBS of the resin cement to the zirconia ceramics ($p < 0.001$). The highest bond strength was recorded in the LRC group. In the CRC group, 75% of the failures were of the adhesive type, compared with 66.7% and 83.3% in the LRC and LGC groups, respectively. In the CGC group, all failures were adhesive.

Conclusions: Pretreatment of zirconia ceramic via Nd:YAG laser improves the bond strength of the resin cement to the zirconia ceramic. GI cement does not provide sufficient bond strength of zirconia ceramics to dentin.

Recently the demand for dental restorations with high strength and good esthetic qualities has increased to such an extent that ceramic materials will replace metal in dentistry.[1] Among dental ceramics, zirconia has gained in popularity, and holds a leading position in metal-free dental restorations because of properties such as high strength, chemical stability, biological compatibility, and nontoxicity.[2-6] Recent progress in computer-aided design and computer-aided manufacturing (CAD/CAM) techniques has made zirconia an ideal and convenient choice for indirect restorations.[7-10]

The success rate of zirconia restorations is not only due to their mechanical and physical properties. Cementation is also an important factor lending to long-term wear and durability.[11-14] In these restorations, the bond strength of cement to zirconia is inadequate. For adequate bonding, micromechanical interlocking or chemical adhesion is needed.[8-10,15] Etching with hydrofluoric acid and silanization are not applicable to zirconia, as there is no silica glassy phase, such as with feldspathic ceramics.[16-19]

Despite much research and numerous studies, cementation in zirconia restorations remains a challenge. Different methods have been recommended for zirconia surface treatment.[20] A clinical recommendation for zirconia-based ceramics is air-abrasion with aluminum oxide particles for increasing surface roughness and mechanical interlocking with resin cement containing modified phosphate monomer 10-methacryloyloxydecyl dihydrogen phosphate (MDP).[21,22] However, the long-term mechanical properties after air-abrasion are unclear because of the risk of zirconia microcracks.[22] Therefore, continuous efforts have been made to increase surface roughness and improve chemical bonding to zirconia.

Lasers have become popular in dentistry for various reasons, such as for treating hypersensitivity, bleaching, sealing pits and fissures, and for removing caries as performed by neodymium-doped yttrium aluminum garnet laser (Nd:YAG).[20-23] With technological advancements, lasers have been used to change the surface so as to improve bonding to dental structures.[24,25] Nd:YAG can enhance bond strength of feldspathic and aluminous ceramics to resin cement.[26] Although there are controversial results for Y-TZP, some studies have recommended lasers such as CO_2, erbium (Er):YAG, and Nd:YAG to induce changes in the zirconia surface to increase bond strength.[6,24,27-29]

The aim of the current study was to determine the effect of Nd:YAG-laser ablation on the shear bond strength (SBS) of a resin cement and glass ionomer (GI) cement to a zirconia ceramic base. The null hypothesis of this study was that surface preparation with an Nd:YAG laser does not increase the shear bond resistance of resin cement and GI cement to zirconia ceramics.

Materials and methods

The present in vitro study was performed on 48 yttrium-stabilized tetragonal zirconia polycrystal (Y-TZP) blocks. The zirconia blocks (4 mm high, 4 mm wide, 1 mm thick; Cercon; Degudent, Hanau, Germany) were prepared using a milling machine (Cerec3, In Lab XL Milling Unit; Dentsply Sirona, York, PA) and a copy milling technique based on the manufacturer's instructions. The specimens were cleaned in an ultrasonic bath containing isopropanol for 3 minutes and dried by air syringe before surface treatment. They were randomly assigned into four groups of 12, as described below.

In the **CRC** group (control), no surface pretreatment was applied for bonding with the resin cement.

In the **LRC** group, bonding surfaces of the zirconia blocks were irradiated by Nd:YAG laser (Fidelis Plus II; Fotona, Ljubljana, Slovenia). The surfaces of the zirconia blocks were coated with graphite prior to laser irradiation to increase energy absorption.[30] The laser beam was used at a 1064 nm wavelength, a 10 Hz frequency, and a 180 μs pulse duration. Laser beam parameters were selected based on the results of previous studies on micromechanical retention.[31] The laser optical fiber (300 μm diameter) was kept 30 mm from the ceramic surface for 60 seconds, and the treatment area was manually irradiated with no water spray. After irradiation, the adhesive tape was removed, and the ceramic pieces were ultrasonically cleaned in 96% isopropanol for 3 minutes and then in distilled water for 2 minutes, and then air-dried.

In the **CGC** group (control), no surface pretreatment was applied for bonding with the GI cement.

In the **LGC** group, the surface treatment for bonding with the GI was performed similarly to the LRC group.

A total of 24 human mandibular molars free of cracks, fractures, or caries were selected, cleaned by scaling, and kept in saline until use. All teeth were embedded in autopolymerized acrylic resin blocks up to the cementoenamel junction. The teeth were mounted in acrylic blocks. Hollow plastic cylinders with an internal diameter of 15 mm, an external diameter of 19 mm, and a height of 18 mm were used to form the acrylic resin blocks holding the teeth. An autopolymerized acrylic resin was used for embedding the teeth. With a carbide burr, buccal and lingual surfaces of all teeth were reduced to remove all the enamel until the dentin was exposed. Finally, 48 smooth dentin surfaces were obtained. For the allocation of specimens in the four test groups, each tooth surface was numbered from 1 to 48, and a computer was used for random selection.

In the CRC and LRC groups, ceramic blocks were cemented to the dentin surfaces using dual-curing resin cement (Panavia F2.0; Kuraray Noritake Dental Inc., Osaka, Japan). First, the A and B primers were admixed and then applied to the surface of the dentin with a microbrush. After 20 seconds, the adhesive layer was gently air dried. Equal amounts of the A/B paste of the resin cement were dispensed and mixed for 20 seconds. This mixture was applied to the ceramic surface and then seated on the surface of the dentin. Excess cement was removed with a dental explorer after the margins were light cured for 5 seconds. Before being washed with an air-water spray, the specimens were light cured for 40 seconds, and an oxygen-blocking gel (Oxyguard II; Kuraray Dental, New York, NY) was applied for 3 minutes.

In the CGC and LGC groups, the GI cement (Fuji I; GC, Tokyo, Japan) was prepared according to the manufacturer's instructions and applied to the ceramic blocks and then seated on the dentin surface. After 1 minute, excess cement was removed using a dental explorer. A continuous load of finger pressure was applied for 3 minutes until the setting of the cement was complete. All specimens in the four groups were stored in distilled water at 37°C for 24 hours before SBS testing. The SBS test was performed using a universal mechanical testing machine (SANTAM-STM-20, Tehran, Iran). Specimens were secured to the lower fixed compartment of the testing machine using tightening screws. The SBS test was performed by a compressive mode of load applied at the ceramic-dentin interface with a mono-beveled chisel-shaped metallic rod attached to the upper movable compartment of the testing machine, traveling at a 1 mm/min crosshead speed. The load required for debonding was recorded in Newtons.

All fractured specimens were evaluated twice under a stereomicroscope (SZ40; Olympus, Tokyo, Japan) at a 30× magnification for fracture modes (cohesive, adhesive, mixed) by one operator. Data were analyzed by SPSS 19. A one-way ANOVA was performed to compare the average bond strength of the four groups. Pairwise comparisons among the groups were obtained using the Games-Howell test. Fisher's exact test evaluated the percentages of adhesive failure among the groups. The level of significance was set at 0.05.

Results

The highest and lowest mean SBS values were observed in the LRC and CGC groups, respectively. The mean SBS values for all groups are reported in Table 1. A one-way ANOVA showed statistically significant differences in the SBS values of the four groups ($p < 0.001$).

Pairwise comparison of the groups using the Games-Howell test showed significant differences between all groups, except for the LGC and CGC groups ($p = 0.060$). There were significant differences between the LRC and CGC groups ($p < 0.001$), LRC and LGC groups ($p < 0.001$), LRC and CRC groups ($p < 0.001$), LGC and CRC groups ($p = 0.001$), and CGC and CRC groups ($p < 0.001$).

An evaluation of each group mode of failure showed that 100% of the fractures in the CGC group were adhesive (between zirconia and cement). In the CRC group, 75% of failures (between the composite resin and resin cement) were adhesive and 25% were mixed. In the LRC group, 66.7% of the failures were adhesive, 8.3% were cohesive, and 25% were mixed. In the LGC group, 83.3% of failures were adhesive and 16.7% were mixed. The association between the mode of failures and group type was not significant (Table 2).

Table 2 Comparison of the group mode of failure

Group	Adhesive (%)	Cohesive (%)	Mixed (%)	*p*-Value
CRC	75	0	25	
LRC	66.7	8.3	25	0.268
CGC	100	0	0	
LGC	83.3	0	16.7	

CRC = control group of resin cement; LRC = laser-treated group of resin cement; CGC = control group of GI cement; LGC = laser-treated group of GI cement.

Discussion

This study evaluated the effect of an Nd:YAG laser on the SBS of resin cement and GI cement to zirconia ceramics. Panavia cement, which is based on an ester phosphate monomer (MDP), was employed in the two study groups because considerable evidence confirms that resin cements modified with MDP have improved bonding to Y-TZP ceramics because of a chemical affinity to metal oxides.[32,33] MDP is an ester phosphate monomer that reacts chemically to zirconia.[34] The results of this study indicate that surface preparation with an Nd:YAG laser increases the SBS of resin cement to a zirconia surface ($p < 0.001$).

It has been suggested that 10 to 13 MPa is the minimum strength needed for clinical bonding.[35,36] This work demonstrated that GI, as cement for bonding zirconia ceramic blocks to dentin, does not have sufficient strength (1.66 MPa and 2.21 MPa in CGC and LGC, respectively). Motohiro et al[37] reported that GI cement has significantly lower bond strength to zirconia in comparison with resin cement.

For satisfactory adhesion and micromechanical retention, there should be acceptable wettability and an adequate surface area. Therefore, surface roughness is a key factor for bonding.[38]

Several studies have investigated the effect of an Nd:YAG laser on the bonding properties of dental ceramics.[39,40] da Silveira et al[39] reported that alumina-based ceramics treated with Nd-YAG lasers show better resin bonding patterns. Li et al[40] found that Nd:YAG lasers can improve the bond strength of adhesive cement to feldspathic porcelain as well as hydrofluoric acid etching. According to the findings of this study, Nd:YAG-laser treatment on a zirconia surface enhanced the bond strength of the resin cement to dentin.

Table 1 Comparison of the shear bond strength of resin cement to zirconia ceramic in groups (MPa)

Group	Mean bond strength*	Standard deviation	Minimum bond strength	Maximum bond strength	p-value
CRC	3.98^{A}	1.10	2.02	5.57	
LRC	10.24^{B}	2.46	7.73	14.33	
CGC	1.66^{C}	0.59	0.82	2.76	<0.001
LGC	2.21^{C}	0.38	1.42	2.85	

CRC = Control group of resin cement; LRC = Laser-treated group of resin cement; CGC = control group of GI cement; LGC = Laser-treated group of GI cement.

*Same letters show a nonsignificant difference.

Nd:YAG-laser irradiation is recommended for treating a ceramic surface due to the formation of a glazed superficial layer.[41] Usumez et al[38] and Spohr et al[42] concluded that the Nd:YAG laser increases surface roughness and improves bonding of Panavia-Fluoro cement to In-Ceram zirconia. Paranhos et al[28] suggested that Nd:YAG-laser treatment increases roughness on zirconia and consequently the SBS of Panavia to zirconia. According to da Silveira et al,[39] the most effective surface treatment was the Nd:YAG laser followed by the Rocatec system and Al_2O_3 sandblasting. These studies are consistent with the current work, in which an Nd:YAG laser enhanced the SBS of resin cement bonded to zirconia ceramics. It should be noted that the increased temperature during laser irradiation can also cause thermal melting of the ceramic surface. The surface expands during melting and immediately contracts during solidification. The stress caused by temperature changes can result in superficial cracks. Another issue to consider is that Nd:YAG-laser-treated surfaces are characterized by a carbonized layer with silver pigments,[28] making it undesirable for esthetic zones. Arami et al[43] concluded that an Er:YAG laser is a suitable alternative for airborne particle abrasion, but that treating a zirconia surface with Nd:YAG and CO_2 lasers can be very destructive, as the generation of extreme heat may adversely affect adhesion and mechanical properties. Akyil et al[27] reported that Nd:YAG-laser treatment improves the SBS of resin cement only in combination with airborne particle abrasion. They suggested that without particle abrasion, the SBS of resin cement was reduced. The assessment of bond strength values is lacking without a study of the modes of failure. Bond failure mode analyses provide critical information about bonding effectiveness. Mixed and cohesive failures are preferred over adhesive failures, because the latter indicates low bond strength.[44] In this study, the type of cement and laser pretreatment did not significantly alter the mode of fracture ($p = 0.268$). It should be noted that the LRC group had the least adhesive failures.

Conclusions

Under the limitations of this study, the treatment of zirconia ceramic surfaces with an Nd:YAG laser significantly increased the bond strength of resin cement to zirconia ceramics.

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