Original Article

Effect of Laser Irradiation on Bond Strength of Zirconia Ceramic to Self-Adhesive Resin Cement

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Abstract

Background and Aim: Bonding of zirconia to resin cement is challenging, and the zirconia surface requires surface treatment to yield an acceptable bond strength. This study aimed to evaluate the effect of different surface treatments on the bond strength of zirconia to a resin cement.

Materials and Methods: In this in-vitro experimental study, 60 zirconia discs measuring 12 mm in diameter and 2 mm in thickness were randomly divided in to six groups of 10: (I) No treatment, (II) sandblasting plus neodymium-doped yttrium aluminum garnet (Nd:YAG) laser (1 W), (III) sandblasting plus Nd:YAG laser (2 W), (IV) Nd:YAG laser alone (1 W), (V) Nd:YAG laser alone (2 W), and (VI) sandblasting. Using a custom-made punch, a V-shaped bonding area with a 4-mm diameter and 90° angle was created in a Teflon tape. Composite cylinders (Filtek Z250) were then fabricated and bonded to conditioned zirconia ceramic using Clearfil self-adhesive luting cement. Specimens were stored in distilled water at 37°C for 24 hours. Then, the specimens were tested for bond strength using a universal testing machine. Data were analyzed using two-way analysis of variance (ANOVA) followed by t-test. One-way ANOVA and Tukey's HSD (honestly significant difference) test were applied for evaluating the effect of the laser.

Results: Sandblasting caused a significantly higher bond strength compared to other methods ($P=0.00$). Among the laser-irradiated groups, Nd:YAG laser (2 W) yielded a higher bond strength ($P<0.05$).

Conclusion: Sandblasting of high-strength zirconia ceramic can significantly increase its bond strength, but no significant difference in bond strength was noted in the laser-irradiated groups.

Key Words: Zirconia, Resin Cements, Low-Level Light Therapy

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Introduction

Zirconia ceramics are increasingly used for the fabrication of fixed and removable partial dentures, implant restorations, and other dental restorations [1]. In cosmetic dentistry, zirconia ceramics with optimal mechanical properties, chemical stability, and biocompatibility are used for the fabrication of

resistant core materials. They are favored by patients due to their natural appearance [2-4].
However, the bond strength between resin cements and zirconia ceramic core is a matter of concern. Unlike feldspathic and lithium disilicate ceramics, zirconia ceramics lack the glass phase and cannot be etched. Surface preparation methods, such as sandblasting, silicoating, etching with hydrofluoric acid, and silanization, affect the quality of the bond since they change the wettability, surface toughness, composition, and chemical behavior of bonding agents. However, none of these methods yield ideal results [5-7].
On the other hand, cements with the ability to bond to a wide range of dental materials, including ceramic surfaces, are ideal in dentistry [8-10]. Self-adhesive cements are becoming increasingly popular since they do not require etching and bonding (in contrast to conventional resin cements that require a primer and an etchant), and thus, incomplete penetration of cement into dentinal tubules and postoperative tooth hypersensitivity are prevented [8-10].
These cements are used for bonding of inlays and onlays and for veneering of ceramic crowns [11]. However, cementation of zirconia and all-ceramic restorations is a multistep process, and bonding surface preparation is required to facilitate it [10,12,13].
Studies have shown that surface preparation of feldspathic porcelain with Nd:YAG (neodymium-doped yttrium aluminum garnet; Nd:$Y_3Al_5O_{12}$) laser enhances its bond strength to adhesive cements compared to hydrofluoric acid-etching [14]. Spohr et al [15] demonstrated that Nd:YAG laser irradiation of zirconia ceramic surface significantly improved its bond strength to resin cements.
Nd:YAG is a crystal used as a lasing medium for solid-state lasers. The dopant, triply ionized neodymium, Nd (III), substitutes a small portion (1%) of yttrium ions in the host crystal structure of yttrium aluminum garnet (YAG) as the two ions have a similar size [1]. The neodymium ion provides lasing activity in the crystal, the same as red chromium ion in ruby lasers [1].
Insufficient data are available on the effect of Nd:YAG laser irradiation of the zirconia surface on its bond strength [16,17]. The aim of this study was to evaluate the bond strength of a self-adhesive resin cement to zirconia ceramic following laser irradiation of the ceramic surface compared to conventional methods.

Materials and Methods

In this in-vitro experimental study, the sample size was calculated to be 10 in each group by selecting the 2-level factorial feature of Minitab software (Version 15; Minitab Inc., State College, PA, USA), assuming $\alpha=0.05$, $\beta=0.2$, and d=350 N. The samples were fabricated according to ISO 6872:2015 [18]. Zirconia blocks measuring 1 cm × 1 cm with a 2-mm diameter were cut out of zirconia ingots (CORiTEC Zr transpa Disc, Shanghai, China) using a shearing machine (Coltolux 75, Coltene/Whaledent, Mahwah, NJ, USA) and were sintered. They were then washed with distilled water for five minutes in an ultrasonic bath and incubated in distilled water at 37°C for 24 hours.
The samples were randomly divided into six subgroups (n=10). No preparation was done in the control group (I). Other groups were treated as follows: (II) Nd:YAG laser (1 W, 10 Hz, 100 mJ), (III) Nd:YAG laser (2 W, 10 Hz, 200 mJ), (IV) Nd:YAG laser (1 W, 10 Hz, 100 mJ) + sandblasting, (V) Nd:YAG laser (2 W, 10 Hz, 200 mJ) + sandblasting, and (VI) Sandblasting. The selection of laser powers was based on a pilot study.
Using a custom-made punch, a V-shaped bonding area with a 4-mm diameter and 90° angle was created in a Teflon tape. A Tygon tubing (Microbore Tubing, Saint-Gobain Performance Plastics, Akron, OH, USA) with a 2-mm diameter and 12-mm length was placed on the bonding area and filled with composite resin (Filtek Z250, 3M ESPE, St. Paul, MN, USA) and light-cured for 40 seconds (QTH Light-Curing device, Ivoclar Vivadent 551730, Zurich, Germany). A composite cylinder was fabricated as such and bonded to the ceramic surface covered with the punched tape using a self-adhesive resin cement (Clearfil SA Luting; Kuraray, Tokyo, Japan). To complete the process of polymerization of the resin cement, the samples were incubated at 37°C for 24 hours. The bond strength was measured using a universal testing machine (Bongshin®, Bongshin Loadcell Co. Ltd., Seoul, Korea) according to ISO

6872:2015 [18] by applying a 50-N load at a crosshead speed of 0.5 mm/minute at a distance of 11 mm from the composite. The bond strength was calculated by dividing the load at fracture to the bonding surface area and was reported in megapascal (MPa).

Data were analyzed using SPSS version 22 (SPSS Inc., Chicago, IL, USA). Two-way analysis of variance (ANOVA) was applied to evaluate the effects of sandblasting and laser irradiation. Because the interaction effect was significant, subgroup analysis was performed. One-way ANOVA and Tukey's HSD (honestly significant difference) test were applied for evaluating the effect of the laser, and t-test was applied for evaluating the effect of sandblasting in each laser group. $P<0.05$ was considered statistically significant.

Results

Table 1 shows the minimum, maximum, mean, and standard deviation (SD) of bond strength in the groups. The highest mean bond strength was found in the sandblasted group (1927.14±572.08 MPa), and the lowest mean bond strength was found in the no-preparation control group (392.27±210.48 MPa). One-way ANOVA showed significant differences between the study groups (P=0.00).

Two-way ANOVA showed the significant interaction effect of sandblasting and laser irradiation on bond strength ($P<0.05$); subgroup analysis in the sandblasted group showed that its bond strength was significantly higher than that of the laser-irradiated groups. But in sandblasting + laser groups, the bond strength of the 2-W Nd:YAG laser group was significantly higher than that of other groups ($P<0.05$).

To compare the bond strength of the groups with and without sandblasting in the laser subgroups, Tukey’s HSD test was applied for multiple comparisons (Tables 2 and 3). The results showed that, among the laser-irradiated groups, no significant difference was found between sandblasted and non-sandblasted groups ($P>0.05$).

Discussion

The results of the present study showed no increase in the bond strength of the groups subjected to laser irradiation and no significant difference in the use of lasers.

In a study conducted by Liu et al [19] on the effect of different surface preparations on the bond strength of zirconia ceramic, the zirconia ceramic samples were divided into 11 groups based on the type of surface preparation. Following surface preparation, the morphological properties and surface roughness were evaluated. All samples were bonded using a resin cement. The shear bond strength test results showed that the highest level of surface roughness was related to higher powers of the laser (2 W and 3 W). No significant difference was observed among the groups with regard to laser parameters. The bond strength of the laser-irradiated and the control groups was significantly lower than the bond strength of the group sandblasted with aluminum oxide particles [19]. Powers less than 1 W failed to create significant surface roughness in our pilot study. However, 1-W and 2-W powers, even in the short-pulse mode, caused destruction, fusion, carbonization, and removal of zirconia ceramic surface structure and leveled the surface by the fusion of superficial crystals. Reduction of porosities (which would help in micromechanical retention) negatively affected the bond strength compared to sandblasting.

In 2010, Osorio et al [20] investigated the impact of different preparation methods on the surface roughness of In-Ceram ceramic. They sandblasted the ceramic blocks with 110-µm aluminum oxide particles. Then, the blocks underwent surface preparation. They showed that none of the preparation methods increased the surface roughness of In-Ceram [20]. Several studies have evaluated the impact of different methods of zirconia surface preparation such as conventional methods or laser irradiation. In many studies, sandblasting with aluminum oxide particles yielded acceptable results [20-23].

An in-vitro study conducted by Ural et al [24] in 2010 evaluated the effect of different methods of preparation, including laser irradiation, on the shear bond strength of resin cements to zirconia ceramic. The zirconia core samples (1-mm tip distance, 2-mm thickness) were prepared and mounted in auto-polymerizing acrylic resin. The shear bond strength was measured using a universal testing machine. The highest shear bond

Table 1. Fracture toughness (MPa) of zirconia ceramic according to surface treatments

Group	Minimum	Maximum	Mean
Control	120.18	730.97	392.26
Nd:YAG laser (1 W)	329.49	1451.73	637.90
Nd:YAG laser (2 W)	704.95	1965.75	1108.92
Sandblasting	1169.07	2949.13	1927.13
Nd:YAG laser (1 W) + Sandblasting	527.77	935.66	679.35
Nd:YAG laser (2 W) + Sandblasting	504.55	1927.42	982.65

Table 2. Pairwise comparisons (Tukey's HSD) of the control and the laser-irradiated groups

-	No treatment	Nd:YAG laser (1 W)	Nd:YAG laser (2 W)
No treatment	-	.30	-
Nd:YAG laser (1 W)	-	-	.04
Nd:YAG laser (2 W)	.00	-	-

Table 3. Pairwise comparisons (Tukey's HSD) of the sandblasted and the sandblasting + laser groups

-	Sandblasting	Sandblasting + Nd:YAG laser (1 W)	Sandblasting + Nd:YAG laser (2 W)
Sandblasting	-	-	.00
Sandblasting + Nd:YAG laser (1-W)	.00	-	-
Sandblasting + Nd:YAG laser (2-W)	-	.18	-

strength was found in the laser-irradiated group, whereas the lowest value belonged to the control group. The results showed that carbon dioxide (CO2) laser treatment, as an effective method, can be used to increase the bond strength of resin cements [24].

Spohr et al [15] used Nd:YAG laser on the zirconia ceramic surface. They concluded that preparation with Nd:YAG laser significantly affected the bond strength of zirconia to resin cements [15]. In 2011, Nikzad et al [22] evaluated the effect of laser and other surface preparations on the shear bond strength of zirconia ceramic to dentin. In their study, Cercon was cemented to dentin after preparation by sandblasting with 50-µm aluminum oxide particles and by CO2 and Nd:YAG laser irradiation. The shear bond strength of the samples was measured, and the mode of failure was determined under a scanning electron microscope (SEM). They showed that surface preparation of Cercon ceramic samples with CO2 and Nd:YAG laser irradiation failed to increase the shear bond strength to human dentin compared to the conventional sandblasting technique. Therefore, application of these methods with the properties and conditions mentioned in their study is questionable for cementing Cercon ceramic to dentin [22].

However, application of each of the preparation methods alone or in combination with another method significantly increased the bond strength compared to the control group, and this result showed that sintered zirconia surface is not suitable for achieving the desired clinical bond strength. These findings are in line with those of most previous studies and indicate that sintered zirconia needs surface preparation to increase its micromechanical retention for achieving a higher bond strength. Also, it has been shown that Nd:YAG and erbium-doped yttrium aluminium garnet (Er:YAG) laser irradiation with different parameters is not suitable for zirconia surface preparation [15,19].
Moreover, despite the advances in laser technology and use of different powers, surface preparation by sandblasting is significantly more effective for increasing the surface roughness and consequently the bond strength. It seems that sintered zirconia crystals are converted to an amorphous state when subjected to laser energy, and the inter-crystalline space is eliminated. This, similar to the sintering process, results in melting of the material and creates a more polished surface compared to sandblasting but more porous compared to sintering. Therefore, it may be concluded that laser may be more effective for surface preparation of other types of ceramics with a higher amount of glass matrix and less amount of crystals. But, this preparation method is not suitable for compressed polycrystalline ceramics such as alumina or zirconia ceramics.

Conclusion

Zirconia ceramic surface preparation significantly increases its bond strength to resin cements compared to no preparation. In this study, sandblasting of high-strength zirconia ceramic significantly increased its bond strength, but laser irradiation caused no significant change in the bond strength.

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