



Effects of Sandblasting and Er:YAG Laser Irradiation for Surface Treatment of Nickel-Chromium Alloy on Its Shear Bond Strength to Composite Resin

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ABSTRACT

Objectives: This study evaluated the effect of different surface treatments of nickel-chromium (Ni-Cr) alloy on its shear bond strength (SBS) to composite resin.

Materials and Methods: In this in vitro study, 45 Ni-Cr discs were fabricated and randomly assigned to three groups (n=15). Group 1 underwent sandblasting with 50µm aluminum oxide (Al₂O₃) particles at 60psi for 10 seconds. Group 2 was treated with Er:YAG laser (500mJ, 10Hz, 5W for 20 seconds). Group 3 received sandblasting followed by Er:YAG laser irradiation. A universal adhesive containing 10-MDP monomer was applied on all specimens, and composite resin cylinders were bonded to the treated metal surfaces. After 10,000 thermal cycles (5°C/55°C), SBS was measured using a universal testing machine. Failure modes were examined under a stereomicroscope at ×40 magnification. Data were analyzed by one-way ANOVA (alpha=0.05).

Results: Significant differences in the mean SBS was observed among the groups (P<0.001). Sandblasting + Er:YAG laser exhibited the highest mean SBS (14.32±1.83MPa), which was significantly greater than that of the sandblasting group (12.73±1.62MPa; P=0.036) and the Er:YAG laser group (6.85±1.60MPa; P<0.001). The sandblasting group also showed significantly higher SBS than the Er:YAG laser group (P<0.001). No significant difference was found in the mode of failure among the groups (P=0.999), with mixed failure predominating in all groups.

Conclusion: Surface treatment of Ni-Cr alloy by a combination of sandblasting with Al₂O₃ particles and Er:YAG laser irradiation produced significantly higher SBS to composite resin than either sandblasting or Er:YAG laser treatment alone.

Keywords: Composite Resins; Dental Porcelain; Lasers; Shear Strength

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INTRODUCTION

Porcelain fused to metal (PFM) crowns are dental prostheses that provide optimal strength, toughness, and esthetics [1,2]. Despite many efforts to strengthen the bond of

ceramic to metal, the most frequently observed issue in PFM restorations is the occurrence of fracture at the porcelain-metal interface [3-5]. The most common reason for replacing PFM restorations is porcelain

breakage and chipping following recurrent caries. The prevalence of porcelain fracture has been reported to be 2-8% [6-8].

Porcelain fracture in PFM restorations is a multifactorial problem [9]. Mechanical failures, environmental factors especially humidity, presence of cracks in ceramics, technical errors during restoration preparation, stresses related to masticatory forces, insufficient tooth preparation, failures related to fatigue, stress applied to restoration, trauma, and stress and strain during chewing are among the reasons mentioned for the fracture of porcelain [10].

Occurrence of fracture in veneering porcelain does not always lead to failure of restoration, and can be repaired directly inside the oral cavity, which is easy and affordable, and provides acceptable function and esthetics [8]. The main challenge in restoration repair is when the porcelain is completely fractured and the underlying metal is completely exposed, as the bond strength between composite and metal is less than the bond strength between porcelain and metal [11-13]. To date, various methods have been introduced to create a strong bond between the metal substrate and resin materials, such as air abrasion with aluminum oxide (Al_2O_3) particles, etching with hydrofluoric acid, use of alloy primers, tribochemical coating method, and laser irradiation [14-19].

Laser is increasingly used in almost all dental fields [20-22]. Erbium-doped yttrium aluminum garnet (Er:YAG) laser with a wavelength of 2940nm is among the laser types used in dentistry [23-25]. It is stated that the micro-explorations created by Er:YAG laser cause thermomechanical ablation and therefore, are effective in creating a retentive surface, and improve the bond strength of composite to metal [26]. The results of Madani et al, [27] regarding the effectiveness of silica-lasing method on the bond strength of composite resin to nickel-chromium (Ni-Cr) alloy showed that the shear bond strength (SBS) in the neodymium-doped yttrium aluminum garnet (Nd:YAG) laser group was significantly higher than that in the airborne particle abrasion group. In another study

conducted by Yilmaz et al, [28] regarding the effect of using metal primers and Nd:YAG laser radiation on the bond strength between chromium-cobalt alloy and polymethyl methacrylate, it was reported that the SBS of the group subjected to sandblasting plus Nd:YAG laser irradiation and application of metal primers was significantly higher than other groups. Shirani et al. and Murray et al. [23,24] in studies on the effect of Ni-Cr alloy surface etching with laser compared to metal surface sandblasting on bond strength to composite resin reported that surface treatment of Ni-Cr alloy with laser increased the bond strength of composite resin to alloy compared to sandblasting.

Considering the gap of information on the efficacy of surface treatment of Ni-Cr alloy by Er:YAG laser, this study aimed to investigate the effect of different surface treatments of Ni-Cr alloy (sandblasting, Er:YAG laser, and sandblasting plus Er:YAG laser) on its SBS to composite resin. The null hypothesis of the study was that the SBS of composite resin to metal would not be significantly different among the study groups.

MATERIALS AND METHODS

The ethics committee of the university approved this in vitro experimental study (IR.GUMS.REC.1399.129). In this study, 45 Ni-Cr discs (Vera Bond Aalba Dent, USA) were fabricated according to the manufacturer's instructions as follows: 45 plexiglass molds were fabricated with 4mm depth and 7mm diameter (Fig. 1A). Then, the wax pattern inside the mold was fabricated with the aforementioned dimensions and after removal from the mold, it was sprayed. Phosphate-based gypsum was used to create investment mold, and then the wax removal process was carried out in the furnace for one hour at 850°C. In the next step, Ni-Cr molten metal (alloy composition: 77.9% nickel, 12.6% chromium, 5% molybdenum, 2.9% aluminum, 1.9% beryllium, and cobalt) was injected into the investment molds by a centrifugal casting machine. After cooling, the metal disc was separated from the investment material. After removing the investment material, any

residue on the specimen surface was removed by silicon carbide strips (400-600 grit) along with water cooling [15]. In the next step, the specimens were mounted in polymethyl methacrylate cubes (Fig. 2A). The metal blocks were randomly divided into 3 groups of 15, and the surface treatment protocol for each group was as follows (Fig. 2B):

In the first group, the specimen surfaces were sandblasted with 50 μ m aluminum oxide particles at 60 psi pressure for 10 seconds at a distance of 10 mm from the surface and at an angle of 45 degrees from the surface. Then, to remove the aluminum oxide powder remnants from the surface, water spray was used for 10 seconds, followed by ultrasonic device for 180 seconds (iSonic F3900; iSonic Inc., Chicago, IL, USA). In the second group, the specimens were treated with Er:YAG laser (Doctor Smile, Vicenza, Italy) irradiation with 500mJ energy, 5W power, and 10Hz frequency for 20 seconds. In the third group, the surface treatment was similar to the first group (sandblasting and cleaning of the specimens were exactly similar to the first group), and then the surface treatment was completed by drying the specimens for 10 seconds with oil-free air spray.

In the next step, universal adhesive (All Bond Universal, Bisco, Schaumburg, IL, USA) containing 10-MDP monomer was applied in all groups in one layer according to the manufacturer's instructions using a microbrush. Then, it was gently air-sprayed in order to reduce the solvent in the adhesive and thin its thickness. Next, it was cured with a

LED curing unit (Bluedent LED Smart Bulgaria) at 1300mW/cm² intensity. Composite resin (Opalis; FGM, Brazil) was then applied into plexiglass molds with 4mm depth and diameter (Fig. 1B).

In order to reach maximum adaptation between the composite resin and the metal surface, the first layer of composite with 1mm thickness was applied and cured for 20 seconds. Then, the second and third layers were placed on the first layer with 1.5mm thickness, and each layer was cured separately for 20 seconds. Finally, to ensure complete polymerization, the entire 4mm thickness was cured for another 20 seconds.

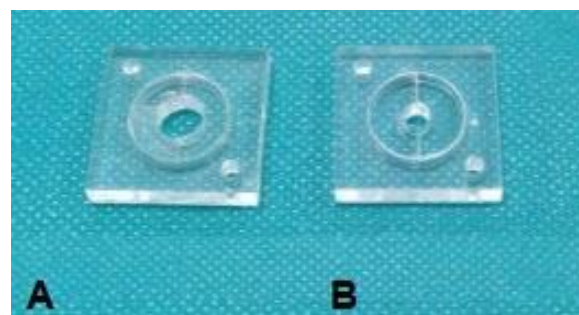


Fig 1. A: Plexiglass molds with 4mm depth and 7mm diameter; B: plexiglass molds with 4mm depth and diameter.

The specimens were kept in distilled water at 37°C for one week. Then, they were subjected to 10,000 thermal cycles in two water baths of 5°C and 55°C (Fig. 3). Every 10,000 cycles is equivalent to one year of aging [5]. The dwell time in each bath was 15 seconds, and the transfer time between the two baths was 10 seconds.

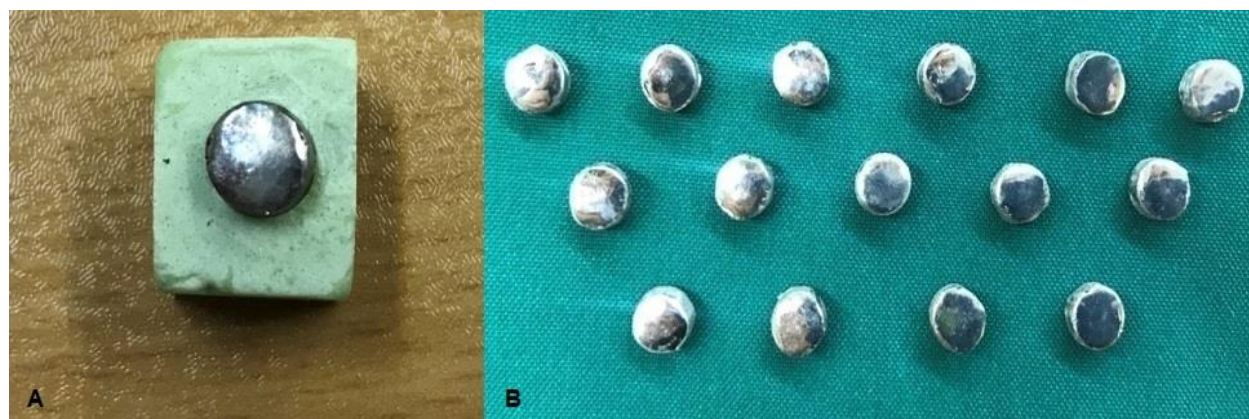


Fig 2. A Metal specimens mounted in polymethyl methacrylate cubes; B: Metal specimens in each study group.



Fig 3. Thermocycler.

The shear test was performed using a universal testing machine (Santam STM-20; Santam Co., Iran). The force was applied at the metal disc-composite resin interface by a stainless-steel blade with a cutting edge with 2.5mm thickness that moved parallel to the bonding interface. The specimens were subjected to shear force at a speed of 0.5mm/min until fracture (Fig. 4). To report the SBS (MPa), the force applied at the moment of fracture was divided by the cross-sectional area of the composite resin, which was 12.56mm.



Fig 4. Specimen in a universal testing machine.

Then, the specimens were assessed under a stereomicroscope (IX-71; Olympus, Tokyo, Japan) at x40 magnification to determine the failure mode, which was categorized as adhesive, cohesive, or mixed. The mode of failure was considered adhesive when more than 90% of the fractures occurred at the metal-composite interface, and was considered cohesive when more than 90% of the fractures occurred within the composite resin or metal. If both adhesive and cohesive fractures were detected in a specimen, the mode of failure was considered as mixed.

The data were analyzed using SPSS version 24. ANOVA was applied for the comparison of groups at a significance level of 0.05.

RESULTS

The SBS of the study groups is presented in Table 1. The highest SBS was reported in the sandblasting/Er:YAG laser group (14.32 ± 1.83 MPa) and the lowest was observed in the Er:YAG laser group (6.85 ± 1.6 MPa).

Table 1. Mean SBS (MPa) of the study groups (n=15)

Group	Mean \pm SD	Min	Max
Er-YAG laser	6.85 \pm 1.6	9.27	4.79
Sandblasting	12.73 \pm 1.62	16.11	9.67
Sandblasting/ Er:YAG laser	14.32 \pm 1.83	17.82	10.99
Total	11.302.64	17.82	4.79

SD: Standard Deviation; Min: Minimum; Max: Maximum.

According to ANOVA, a significant difference was found in SBS among the surface treatment methods ($P < 0.001$) such that the SBS was significantly higher in the sandblasting/Er:YAG laser group than the Er:YAG laser ($P < 0.001$) and sandblasting ($P = 0.036$) groups. Also, the SBS of the sandblasting group was significantly higher than that of the Er:YAG laser group ($P < 0.001$).

According to the Chi-Square test, no significant association was observed between the failure

mode and the surface treatment method

($P=0.999$, Table 2, Fig. 5).

Table 2. Mode of failure in the study groups

Study group	Adhesive	Mixed	Cohesive
Sandblasting	6.7% (1)	93.3% (14)	0% (0)
Er:YAG laser	0% (0)	100% (15)	0% (0)
Sandblasting/ Er:YAG laser	0% (0)	100% (15)	0% (0)
Total	2.2% (1)	97.8% (44)	0% (0)

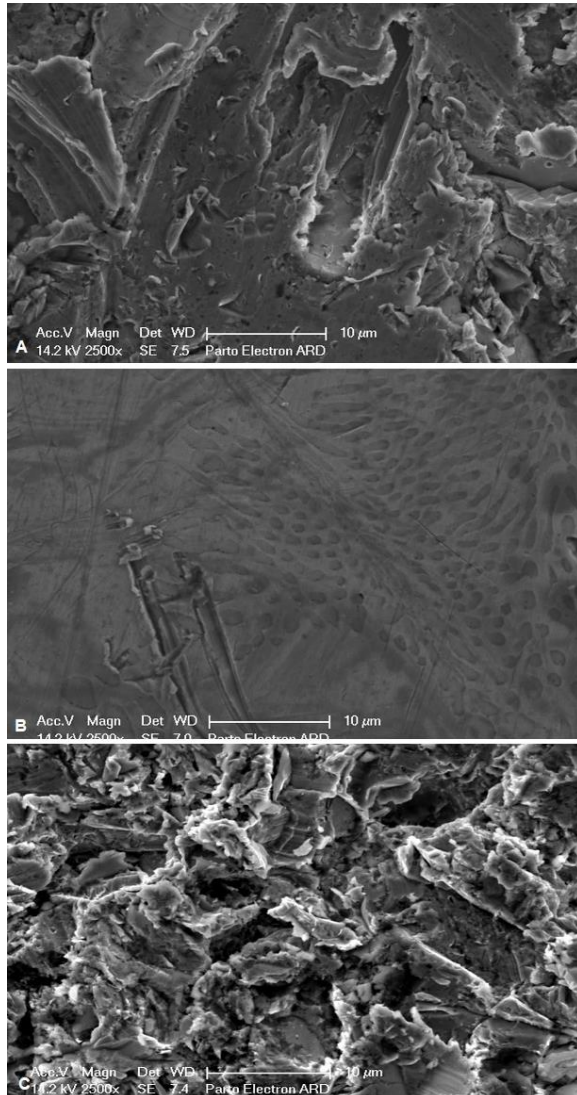


Fig 5. Black spots on the surface are due to impurities in the coating and gas holes. A: In the Sandblasting/Er:YAG laser group, the rough surface is visible at x2500 magnification and 10- μ m scale; B: In the Er:YAG laser group at x2500 magnification and 10- μ m scale, it can be seen that the surface roughness has decreased compared to the sandblasting group alone and sandblasting/Er:YAG laser group; C: In the sandblasting group, the surface roughness is more than that in the Er:YAG laser group and is comparable

to the sandblasting/Er:YAG laser group.

DISCUSSION

In this study, a significant association was found between the SBS and the surface treatment method, such that the highest SBS was observed in the specimens subjected to sandblasting/Er:YAG laser irradiation, and the lowest was observed in the specimens treated with Er:YAG laser.

Duran et al. [29] claimed that the mean bond strength in the sandblasting group (with aluminum oxide powder) was significantly higher than that in the Er:YAG laser group. Similarly, in the current study, the SBS in the sandblasting group (with aluminum oxide powder) was significantly higher than that in the Er:YAG laser group. It may be stated that sandblasting with aluminum oxide powder removes surface contamination and increases surface roughness, resulting in mechanical attachment of resin to metal. However, Er:YAG laser is not as effective as sandblasting since Er:YAG laser causes metal surface ablation and creates a series of fine crater-like scratches on the metal surface. Also, laser reflection from the polished metal surface can reduce the power density of laser on metal surfaces. This explains why the SBS was higher in the sandblasting group than the laser group [29,30-33].

Based on the results of Murray et al, [24] it was determined that a combination of laser and sandblasting (with aluminum oxide powder) significantly increased the mean bond strength between the Ni-Cr alloy and composite resin compared to the sandblasting and laser groups. In agreement with their results, the current study also found that the SBS was significantly higher in the sandblasting/Er:YAG laser group compared to the Er:YAG laser group and the sandblasting group. For interpretation of this result, it can be stated that the sandblasting/Er:YAG laser group

benefits from the advantages of both surface treatment methods. Sandblasting removes the contaminated surface layers, increases surface roughness, and creates a larger surface area for bonding. Also, due to the surface roughness created by sandblasting before laser irradiation, the problem of light reflection from the polished metal surface is resolved. As a result, its negative effect on the power density of laser is eliminated, and laser irradiation can play a more effective role in metal surface treatment. Therefore, a combination of sandblasting and laser radiation can lead to more effective surface treatment and higher bond strength than sandblasting or laser irradiation alone [24,33,34].

In the current study, to determine the mode of failure, the specimens were evaluated under a stereomicroscope. The mode of failure was mixed in all specimens in the Er:YAG laser and sandblasting/Er:YAG laser groups, and mostly mixed in the sandblasting group. There was no significant difference among the groups in this respect. Yilmaz et al. [28] reported that in the sandblasting and sandblasting/Nd:YAG laser groups, the failure mode was predominantly adhesive, while the failure mode was mostly mixed in the sandblasting/metal primer and sandblasting/Nd:YAG laser/metal primer groups. Metal primers have functional monomers in their composition, including MDP, which provides the possibility of bonding to different substrates such as metal, and leads to the improvement of bond strength to metal. Therefore, the obtained results can indicate the effective role of metal primers in improving bond strength and the more frequent occurrence of mixed failures [24,28].

This *in vitro* study has several limitations that should be considered when interpreting the results. First, as with most laboratory-based studies, the experimental conditions cannot fully simulate the complex intraoral environment, including continuous exposure to saliva, pH fluctuations, microbial activity, and dynamic occlusal forces. Although 10,000 thermal cycles were performed to simulate approximately one year of aging, this artificial aging protocol remains limited compared to long-term clinical service.

Second, the sample size ($n=15$ per group) was

relatively modest, which, although sufficient to detect statistically significant differences, may limit the generalizability of the findings. Only one type of nickel-chromium alloy, one universal adhesive (containing 10-MDP), and one composite resin were tested. Therefore, the results may not be directly applicable to other base metal alloys, different adhesive systems, or restorative composites.

Third, although the Er:YAG laser parameters were selected based on previous studies, only one specific set of laser settings (500mJ, 10Hz, 5W for 20 seconds) was evaluated. Different energy densities, pulse durations, or irradiation times might yield different outcomes. Additionally, although surface roughness was qualitatively observed via SEM (as shown in Figure 5), quantitative surface analysis (e.g., Ra values using profilometry or atomic force microscopy) and chemical characterization (e.g., EDS or XPS) were not performed, limiting a deeper understanding of the underlying mechanisms.

Finally, only shear bond strength was measured. Other mechanical tests, such as tensile bond strength, fatigue resistance, or microleakage evaluation, could provide a more comprehensive assessment of the bonding interface.

Future research should focus on translating these findings into clinical relevance. Randomized controlled clinical trials are necessary to evaluate the long-term performance of intraoral repairs of metal-ceramic restorations using the combined sandblasting + Er:YAG laser protocol. Longer aging protocols (e.g., 20,000–50,000 thermal cycles combined with mechanical loading) and the inclusion of fatigue testing would better simulate years of clinical service.

Additional studies should investigate the effect of varying Er:YAG laser parameters to optimize the protocol and explore whether lower or higher energy settings could further improve results or reduce treatment time. The combination of sandblasting + Er:YAG laser with different metal primers or silane coupling agents also warrants investigation, as chemical bonding may further enhance durability.

Comparative studies involving other base

metal alloys (e.g., cobalt-chromium), zirconia, or titanium, as well as different generations of universal adhesives, would broaden the applicability of the findings. Advanced surface characterization techniques and failure analysis at higher magnifications (e.g., SEM/EDX) should be incorporated to better elucidate the micromechanical and chemical interactions at the interface.

Finally, from a practical clinical perspective, studies evaluating the operator time, cost-effectiveness, and technique sensitivity of the combined sandblasting + Er:YAG laser approach compared to conventional methods would be valuable for evidence-based decision-making in repair protocols.

CONCLUSION

The SBS obtained in the Er:YAG laser group was significantly lower than that in the sandblasting group. From this, it can be concluded that surface treatment with Er:YAG laser cannot be a suitable alternative for improving the SBS between Ni-Cr alloy and composite resin compared to surface treatment by sandblasting with aluminum oxide powder. Surface treatment by sandblasting with aluminum oxide powder plus Er:YAG laser irradiation led to significantly higher SBS between composite resin and Ni-Cr surface compared to the Er:YAG laser alone and sandblasting alone.

CONFLICT OF INTEREST STATEMENT

None declared.

GENERATIVE AI IN SCIENTIFIC WRITING

No AI has been used in the preparation of this manuscript.

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