Comparison of the Effect of Nd:YAG Laser and Sandblasting on Shear Bond Strength of a Commercial Ni-Cr Alloy to Porcelain

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Abstract

Introduction: Failures might occur at metal–porcelain interfaces as a problem with metal–ceramic restorations even with the application of airborne-particle abrasion technique. This study was undertaken to evaluate the effect of Nd:YAG laser treatment on the bond strength of porcelain fused to metal. **Methods:** Twenty-four cylindrical specimens (4 mm in diameter and 4 mm in height) were made of a commercially available nickel–chromium alloy by lost-wax technique. Half of the specimens were surface-treated by air-borne particles and the other half was irradiated with Nd:YAG laser beams (wavelength of 1064 nm, energy and frequency of 120 mJ and 10 Hz, respectively, and a power setting of 6 kW). All the specimens (air-abraded and laser-treated) were covered with a 4-mm layer of opaque porcelain in two-stage baking and subjected to shear bond strength test (a 10-kgf at 1 mm/min) until fracture occurred. A fractured specimen from each group was evaluated using scanning electron microscopy. T-test was used for statistical analysis and statistical significance was set at $P<0.05$. **Results:** Shear bond strength was higher in the sandblasted group compared to the laser-etched group ($P<0.05$). **Conclusion:** It can be concluded that Nd:YAG laser irradiation increases the shear bond strength of Ni-Cr alloy to porcelain, but further studies should be carried out to evaluate the effect of different parameters of Nd:YAG laser treatment on shear bond strength**.**

Key words: Crowns, dental prosthesis, lasers, dental porcelain, nickel-chromium-beryllium alloy, aluminum oxide.

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Introduction

Although there is a tendency in modern dentistry to use metal-free restorations, since metal-ceramic restorations exhibit excellent clinical performance, low cost when compared with metal-free restorations, simple cementation technique, and natural reproduction of the lost dentition in most restorative treatments, they are still most frequently used in fixed partial dentures (FPD) and single crowns (1). Furthermore, since the flexural strength of all-ceramic restorations do not permit fabrication of multiple-unit restorations, extensive oral rehabilitations could only be achieved by metal–ceramic FPDs (2). Metal–ceramic prostheses have been used in dentistry with good clinical performance, acceptable esthetics and durability. These restorations combine the fracture resistance of metal substructure with the aesthetic properties of the ceramic (3, 4).

Metal–ceramic prostheses must have satisfactory bond strength of the metal substructure to porcelain to exhibit clinical longevity. Due to the high cost of precious alloys, since the 1970s and after progresses made in ceramic technology, base metal (Ni–Cr and Co–Cr) casting alloys are often selected (5). Nickel–chromium (Ni–Cr) dental alloy has been used to prepare metal-ceramic crowns and fixed partial dentures more commonly. Its mechanical properties enable the fabrication of restorations with a satisfactory hardness with lower thickness. The thermal expansion coefficient of Ni–Cr dental alloy is matched to that of conventional porcelain (6).

Even though this kind of restoration has a metal substructure, it is prone to failures that could occur predominantly at the metal–porcelain interface (1). To improve the bond strength between the metal and ceramic, some surface treatments have been studied to increase the wettability of the metal by porcelain, and also to control the formation of a thin layer of oxides. The principal treatments used include peroxidation of the metal before porcelain application, application of bonding agents, airborne-particle abrasion, degasification, heat treatment, and mechanical retention with carbide burs and diamond mounted tips and also laser treatment (1, 7). It appears there is agreement that the highest bond strength is obtained with acid etching or airborne-particle abrasion (50 μm alumina) in nickel–chromium alloys (8). The possibility of surface contamination with alumina particles that could weaken the bond between porcelain and metal has also been reported (9).

Since the ruby laser was developed by Maiman in 1960, lasers have been widely used in medicine and dentistry. The technological advances during the last decade have been directed toward clinical applications of lasers as an alternative to acid etching of enamel or dentin for bonding dental materials to tooth surfaces. Currently, a number of laser wavelengths are used in oral surgery and dentistry, including CO_2, Nd:YAG, diode and Er:YAG. Also lasers are used to weld metals such as titanium (10, 11) to surface cladding of implants (12), and in laser rapid forming method (13). Among the methods mentioned above to improve the bond strength between metal and porcelain, laser etching is a surface treatment that controls micro-topography more easily because of its depth penetration depending on the material irradiated and provides more surface roughness and a stable surface morphology (14). As diode and CO_2 lasers are used for soft tissue procedures, Er:YAG laser treatment is not an alternative for airborne-particle surface treatment, the laser-etching method may overcome the problem of surface contamination resulting from airborne-particle abrasion, and laser treatment may be a suitable alternative to airborne-particle abrasion or other surface treatment methods to improve the bond strength of dental materials to metal surfaces; in addition, Nd:YAG laser treatment was effective in improving the shear bond strength of porcelain to titanium (9). Therefore we planned this study to evaluate the effect of Nd:YAG laser etching (at a wavelength of 1064 nm, energy and frequency levels of 120 mJ and 10 Hz, respectively and a power setting of 6 kW) on nickel–chromium alloy and its bond strength to porcelain in comparison with airborne-particle abrasion (50-µm alumina particles). A control group was included as it is a conventional method.

Materials and Methods

A total of 24 cylindrical molds measuring 4 mm in height and 4 mm in diameter (ISO 9693) were made of Duralay resin (Pattern Resin LS, GC America, Alsip, IL (Fig.1). Duralay resin patterns were invested with phosphate-bonded investment (Deguvest L, Degudent GmbH, Rodenbacher, Germany) in casting rings. The nickel–chromium casting alloy (Thermabond Alloy Supercast, MFG, Los Angeles, CA, USA) was casted using a gas-oxygen torch and casting machine. After the red glow disappeared from the bottom, the casting ring was plunged under running cold water to disintegrate the investment. The residue of the investment was eliminated with a toothbrush and the final traces were removed ultrasonically. To eliminate metallic oxides, the castings were pickled in 50% HCL. Supercast casting alloy is composed of 75% nickel, 15% chromium and 5% molybdenum. Then the metal excess was eliminated by carbide discs and burs. Then the specimen sizes were standardized with a digital caliper accurate to ±0.1 mm (Digital Caliper, Guanglu, Strikhlu, Germany) and if necessary corrected by a diamond bur. Twelve cylindrical specimens' surfaces were air-abraded with 50-µm alumina particles under a pressure of 3–4 bars and a distance of 10 mm for 10 seconds as a gold standard. The rest of the cylindrical specimens were surface-treated with Nd:YAG laser (at a wavelength of 1064 nm, energy and frequency levels of 120 mJ and 10 Hz, respectively, and a power setting of 6 kW) (Neolaser L, Girrbach Dental Systems, Pforzheim, Germany) by means of a glass fiber with linear movements perpendicular to the surface. Porcelain (Duceram Kiss, Degu Dent, Hanau-Wolfgang, Germany) was baked on specimens as follows. First a thin layer of the bonding agent was applied to the metal surface with a brush and baked. Then the powder and fluid of the opaque porcelain was mixed on a glass slab and the metal surface was coated to a height of 4.8 mm due to the baking shrinkage (%20) by a fine sable brush. The porcelain layer height was standardized by a polyethylene template. Excess liquid was eliminated after gentle vibration and the porcelain was baked according to the manufacturer's instructions. Then porcelain shrinkage was corrected by application of a second layer of porcelain. At this stage, the dimensions were evaluated by a digital caliper and if necessary corrected by diamond burs. Then the specimens were mounted in a universal testing machine (Hounsfield 5KS, England) by Duralay resin. A standard mechanical test was applied on the specimens to measure the shear bond strength as follows. A shear force of 10 kN was applied to the metal–porcelain interface at a crosshead speed of 1 mm/min by a special blade parallel to the metal–ceramic interface until it fractured. The amount of the applied force was shown on the monitor of the machine. This test was repeated for all the 24 specimens and the applied force (MPa) was recorded. The results were statistically analyzed with t-test. Then a fractured specimen's surface in each group was evaluated under a scanning electron microscope (SEM, VEGA/TESCAN) to determine the fracture mode: adhesive or cohesive.

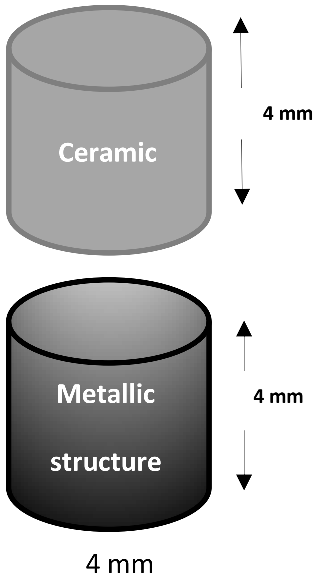

Figure 1. The shape of specimens

Results

Kolmogorov-Smirnov test showed normal distribution of data in this study. Data were also statistically analyzed with independent t-test. The mean bond strength and standard deviation values of shear bond strengths in ceramic bonded to Ni-Cr metal alloy are presented in Table 1. There was a statistically significant difference ($P<0.05$) in shear bond strength values with respect to the type of surface treatment ($P=0.000$). The mean bond strength value in the sandblasted group was 44.203±13.9837 Mpa, which was higher than that in the laser-etched group (27.186±2.648 Mpa). SEM evaluations are given in (Fig. 2 and 3). Failure mode was cohesive in both sandblasted and laser-etched specimens. Statistical analysis of this study showed that the sandblasted group exhibited higher shear bond strength than the laser-etched group.

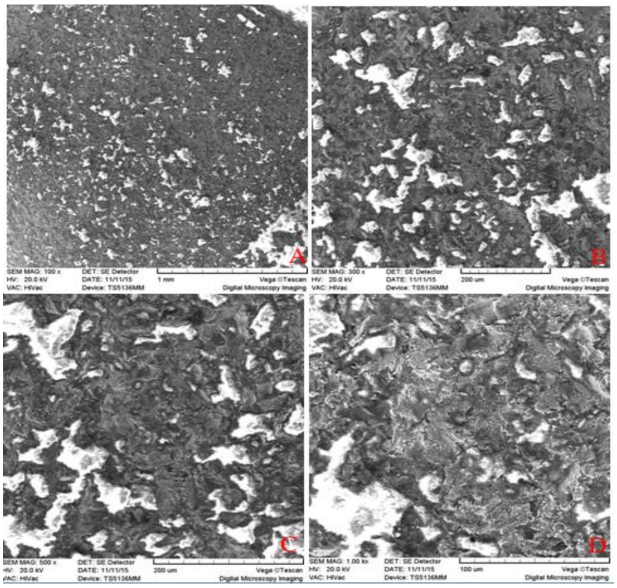

Figure 2. SEM images of the fractured surfaces of sandblasted specimens (×100, ×300, ×500 and ×1000 magnifications).

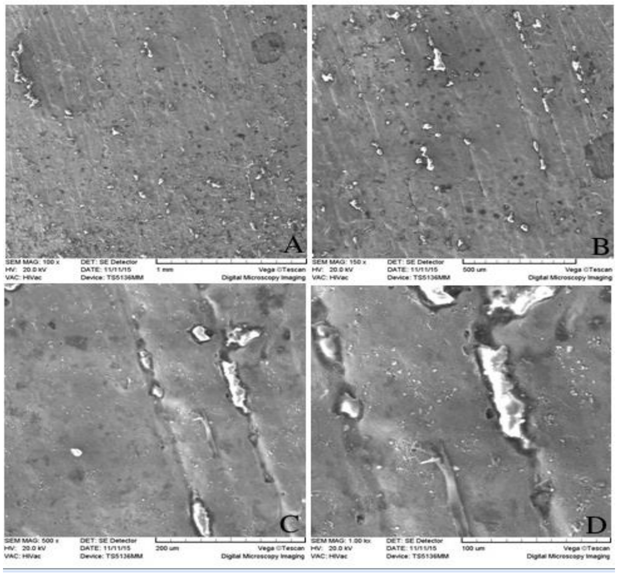

Figure 3. SEM images of the fractured surfaces of laser-treated specimens (×100, ×150, ×500 and ×1000 magnifications).

Discussion

The null hypothesis was rejected based on the results of this study. Among the two groups, sandblasted specimens exhibited significantly different shear bond strength values than the laser-etched ones ($P<0.05$). Sandblasting was a more effective treatment compared to laser etching for improvement of the shear bond strength between metal and ceramic.

The clinical performance of metal–ceramic fixed dental prostheses is usually estimated by the mechanical strength tests of the specific ceramic to the metal substrate (1). A new method of treating implant surface is laser processing that is used to produce adequate surface roughness with a high degree of purity in comparison with other surface treatment methods (5, 15). Cho and Jung (16) demonstrated that laser etching is an effective method for producing an appropriate surface roughness for titanium. Wagner reported that laser and electron-beam thermal treatments could be used to modify the microstructure of titanium surfaces without contamination, providing optimal roughness (9).

Kara et al (17) tested the effect of three different surface treatments on roughness and bond strength in low-fusing ceramics to evaluate which one is more effective in creating the highest retention for ceramic restorations to resin cement. They used air abrasion with alumina particles, acid etching with 5% HF and Nd:YAG laser irradiation (energy and frequency levels of 100 mJ and 10 Hz, respectively). They measured surface roughness by profilometry and examined the specimens with scanning electron microscopy (SEM). Then the luting cement was bonded to the ceramic specimens. They concluded that the air-abrasion method created rougher surfaces compared to the other methods and also the highest shear bond strength. There were no significant differences in surface roughness and shear bond strength between HF acid etching and Nd:YAG laser treatment. Therefore, air abrasion of low-fusing porcelain surfaces is effective in improving the bond strength as compared to the acid-etching and laser irradiation methods.

Kim et al (9) studied the effect of Nd:YAG laser (energy and frequency levels of 120 mJ and 50 Hz, respectively) on shear bond strength at the titanium–ceramic interface in comparison with machining, airborne-particle abrasion with alumina particles and acid etching with 10% HCl. They used a universal testing machine to test the shear bond strength. Ra value and SEM analysis were used for just a specimen from each group before and after the shear bond strength test to evaluate the nature of the fractured surface. They demonstrated that laser etching of titanium surfaces using an Nd:YAG laser is effective in improving titanium–porcelain bond strength as compared to machining and acid etch technique, but laser etching with a low Ra value showed no significant difference in shear bond strength in comparison with airborne-particle abrasion surface treatment.

According to the literature, there is no test that can be considered as ideal for the evaluation of the bond strength of porcelain to metal. Several authors introduced the shear test as the most adequate test to measure the bond strength of porcelain to metal (18).

In this study, a common nickel–chromium alloy was used due to its excellent marginal integrity and no adverse reactions. This alloy has satisfactory mechanical properties such as elasticity, tensile strength and hardness (3, 19). To treat the surface, airborne-particle abrasion (sandblast technique) was used in control group and also Nd:YAG laser treatment (a wavelength of 1064 nm, energy and frequency levels of 120 mJ and 10 Hz, respectively) was used in the study group. Mean shear bond strength between porcelain and metal was estimated at 44.203±13.9837 Mpa for the sandblasted group and 27.186±2.648 Mpa for the laser-etched group.

In accordance with ISO standards 9693 (9), an appropriate bond between a metal alloy and ceramic occurs if shear bond strength is higher than 25 MPa. It suggests clinically acceptable values for this study. Therefore both the control and study groups showed adequate bond strength, but when statistically analyzed, the sandblasted specimens showed significantly higher rate in comparison with the laser-etched group.

The SEM analysis in this study showed that porcelain is mechanically engaged in porosities that are responsible for adhesion and mechanical strength of porcelain bonded to metal. SEM image of the fractured surface of sandblasted specimens (Figure 2) showed a higher amount of porcelain remaining on the metal surface as there was lower amount of porcelain remaining on the grooves created by laser application (Figure 3). Therefore it was consistent with the results of the shear bond strength test. Also it should be noted that laser irradiation resulted in fewer grooves and lines on specimen surfaces. In other words, surface density of grooves and porosities generated by laser etching was lower in comparison with the sandblasting method. Therefore, if laser treatment would be corrected to increase the density of surface grooves, it would probably increase the metal–ceramic bond strength. Failure mode was cohesive in both sandblasted and laser-etched specimens.

The limitations of this study were lack of evaluation of the effects of different parameters on improving the bond strength and application of laser irradiation manually. The types of porcelain and metal alloy used were limited. Also the in vivo condition could not be simulated.

To have a successful and long-term bond, deep knowledge about pre-treatment techniques should exist and a proper technique should be used in order to control the procedure. Selection of a reliable bonding system and standardization of the surface treatment technique are the most important factors for achieving the highest bond strength.

Table 1. Means and standard deviations of shear bond strength values

Group	N	Mean	Standard deviation	Median	Max	Min
Sandblast	12	44.203	13.9837	48.135	64.62	15.43
Laser	12	27.186	2.648	26.89	31.02	23.57

Conclusion

Although there were limitations in this study, the following conclusions were made. The shear bond strength between ceramic and Ni–Cr alloy using laser surface treatment was 27.186±2.648 Mpa. According to ISO standard 9693, Nd:YAG laser treatment can be used to treat the surface of metal substructure in metal–ceramic restorations, but further studies should be carried out to evaluate the effects of output energy, frequency and spot size of Nd:YAG laser on shear bond strength.

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