BASIC SCIENCE RESEARCH

Shear Bond Strength Evaluation of Different Veneering Systems on Ni-Cr Alloys

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Purpose: The aim of this study was to evaluate the shear bond strength of four esthetic veneering materials on nickel-chromium (Ni-Cr) alloy.

Materials and Methods: Forty square patterns (10 × 10 × 1.5 mm) were cast with Ni-Cr, divided equally into four groups, and received four treatments for veneering: conventional porcelain-fused-to-metal (PFM), Artglass, Targis/Vectris, and Biodent light-cured prosthodontic composite resins. After sandblasting of the cast metal surfaces with 50 μm alumina, the composites were applied to the surfaces according to manufacturers' recommendations. Shear bond strength was determined at a crosshead speed of 0.5 mm/min. Results were analyzed statistically with Kruskal-Wallis analysis of variance and multiple comparison tests.

Results: Mean shear bond strength values were 34.96 MPa for PFM, 14.17 MPa for Targis/Vectris, 13.64 MPa for Artglass, and 10.56 MPa for Biodent. The PFM group exhibited significantly higher bond strength values compared with the other three groups ($p < 0.001$).

Conclusion: PFM showed considerably higher shear bond strength values than the three metal-resin bonding techniques.

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INDEX WORDS: bonding systems, composite resin, fixed prosthodontics, resin bonding, shear bond strength

THE METAL-CERAMIC CROWN application has been a successful dental restoration for more than 30 years and the most popular complete artificial crown; however, questions remain about the optimal condition of the alloy surface during application of opaque porcelain and firing procedures.

In recent years highly filled resins have become alternatives to porcelain as veneering material for crowns and fixed partial dentures.[1-5] The advantages of light-cured veneering materials include favorable esthetics, abrasion similar to that of natural tooth substance, reparability, and fast, simple laboratory procedures.[1]

The resin can be retained on the casting by mechanical or chemical means or a combination of both. Until recently, bonding of resin veneer to metal was by mechanical retention. This retention required beads, wires, or loops in metal design.[6] These designs mechanically enhance the attachment of the resin composite to the cast frameworks; however, this process results in a bulkier framework that is difficult to opaque because of the pooling around the beads, with a decrease in retention. Because of insufficient chemical bonding between the metal framework and the veneering material, a gap of as much as 20 μm between the metal and the veneer is developed. Oral fluids fill the gap allowing discoloration and odors to develop, destroying the esthetics of the veneer.

Chemical bonding is more desirable than mechanical bonding. Various methods to chemically enhance the resin/metal bond have been introduced with various metal primers.[1,6-10] These techniques usually involve some pretreatment of the alloy surface with chemical agents. The phosphoric and carboxylic acid functional monomer used in most of these adhesive opaque resins and promoters was effective in bonding composite resin in base dental alloys. Bonding to the base metal alloys has considerably improved with the use of water-resistant carboxylic or phosphoric

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acid derivatives.[1] The Artglass system, a light-polymerized "polymer glass," has been developed as an alternative veneering material for cast-fixed prostheses. The advantages of polyglass Artglass are easy handling, toughness, color stability, wear resistance, plaque repellence, reparability, simple shade concept, and multiple application.[5,11,12] Artglass is composed of three glass or glass-like (vitroid) components. The material not only contains very fine barium aluminum silicate glass particles and a rheological active silica gel, but also so-called organic glass. This organic glass consists of finely triturated, multifunctional, high-molecular methacrylic acid esters that form a very dense network and amorphous structure similar to organic glass. Until now, this kind of structure could not be brought about in this manner with conventional monomer matrices.

Due to the combination of two organic glass or glass-like components by light-curing the multifunctional reactive methacrylate components, a special composition is created that can be called polymer glass.

In the Targis system, phosphoric acid functional monomer is used in the adhesive opaque resin and promoters. A layer of metal oxides or passive film is created on the casting metal surface. Ohno et al defined such a layer as a passive film of hydrated chromium oxyhydroxide and generalized it by the formula: $CrOx\ (OH)_3 \cdot 2nH_2O$, which can be formed on various metals.[13] The phosphoric acid derivative that is contained in the Targis link contains polar terminations, which will bond to the oxide layer formed on the metal surface.

Silane bonding agents are successful in bonding ceramic glass filler particles to the resinous matrix; however, they are ineffective in bonding composite resin to metal because of the lack of suitable bonding sites on the metal such as Si-OH or Al-OH groups. The advantages of Biodent are its elasticity, ease of handling, and its shade match. The disadvantages are that it is contraindicated on occlusal surfaces, plaque-adherence is high, and it has color instability.[3,14] Surface treatment of the metal by sandblasting with Al_2O_3 particles (50 μm) increases the surface area of the metal as well as the composite resin-metal bond strengths.[6] According to Yoshida et al[15] metal sandblasting with Al_2O_3 particles can form a passive film made of Ni, Cr, and Co oxides. Metal primers have an affinity for this layer of oxides. These reactive groups contain polar terminations which will bond to the oxide layer formed on the metal surface.

The purpose of this study was to evaluate the shear bond strengths of four esthetic veneering materials to nickel-chromium (Ni-Cr) alloy.

Materials and Methods

The veneering materials used are summarized in Table 1. Ten alloy specimens were used for each experimental group (Wiron 99, Bego, Bremen, Germany: Ni 65%, Cr 22.5%, Mo 9.5%, Nb 1%, Si 1%, Fe 0.5%).

Table 1. Materials Used

			Composition	
Material	*Manufacturer*	*Polymerization*	*Monomer*	*Filler*
Artglass	Heraeus Kulzer (Wehrheim, Germany)	Light UniXS (Kulzer)	Methacrylic acid ester	UDMA 30 wt%, rheologic active silica (0.07 μm) 15 wt%, silicate glass (0.07 μm) 55 wt%
Targis	Ivoclar (Schaan, Liechtenstein)	Light Targis Quick (Ivoclar) UDMA Targis Power (Ivoclar)	Bis-GMA	Bis-GMA 20wt%, silicate glass (0.03-1μm) 80 wt%
Porcelain	VMK 95 (Vita, Vident, Brea, CA)	NA	Al_2O_3 14-19 wt%, SiO_2 52-68 wt%, K_2O 10-13 wt%	
Biodent Plus	Dentsply De trey GmbH (Konstanz, Germany)	Chemical cure	Powder: Polymethyl metacrylates; liquid: methyl metacrylates	

A commercially available Ni-Cr alloy was used in this study. The alloys were cast with a centrifugal casting machine (Shofu Argon Caster DX, Shofu Dental Mfg Co, Kyoto, Japan) in 10 × 10 × 1.5 mm plates with phosphate-bonded investment (Multi-Vest, Dentsply Int, York, PA).

The alloy specimen was made by grinding the alloy surface with a #400 grit sandpaper to create a flat surface. Specimens were then sandblasted (Micro-etcher, Model ERC, Danville Engineering Inc., Danville, CA) with 50 μm aluminum oxide particles for 15 seconds. The emission pressure was 0.5 MPa with the nozzle 5 mm from the metal surface. After sandblasting, the specimens were ultrasonically cleaned for 1 minute in a distilled water bath and air dried, then received four treatments for veneering. The veneering materials were applied on half the metal surface.

Sample Preparation

Porcelain-fused-to-metal Specimens. VMK 95 (Vita) metal-fused porcelain was used for the study as a control group. The oxidation cycle consisted of heating the specimens from 649°C to 1010°C in a vacuum and sustaining that temperature again in a vacuum for 10 minutes to create an oxide layer. A thin wash layer of opaque was applied on the metal surface, followed by a second and a third opaque layer and three dentine body layers, each of them fired separately according to the manufacturer's instructions. The overall thickness of the balled porcelain layers was 3 mm. Before each application, specimens were placed in a silicone mold to shape the porcelain furnace (Jelenko Commodore VPF; Jelenko Dental Health Products, Armonk, NY).

Artglass Specimens. The metal surface was masked with a double-layer opaquer (Heraeus Kulzer, Wehrheim, Germany) of approximately 150-μm thickness. The opaque was light-polymerized with a light-curing unit (UniXS, Heraeus Kulzer) for 180 seconds, and 3 mm dentin was applied.

Artglass dentin and enamel resins were shaped on the metal surface as two layers and polymerized using Teflon matrices for 90 seconds each in the UniXS before applying the next layer. Dentin paste was applied with an instrument, and the shape was modeled with a brush. Each layer had to be polymerized individually. After applying the enamel layer in the upper third, the final polymerization cycle, lasting 3 minutes in the UniXS apparatus, was performed. Hardened excess Artglass was removed with carbide finishing burs (Diatech, Coltene AG 9450, Altstatten, Switzerland).

Targis/Vectris Specimens. After air-abrasion, the metal surfaces were treated with primer (Targis Link, Ivoclar, Schaan, Liechtenstein) with a single brush application, which was allowed to dry for 5 minutes. Three thin layers of opaque resin were then applied, and each layer was prepolymerized for 20 seconds in the Targis Quick Light-curing unit (Ivoclar) with a final cure of 11 minutes in the Targis Power light-curing unit. Finally, three layers of dentin composite with a maximum thickness of 1 mm each were applied. After that, the specimens were coated with a gel (Targis Gel, Ivoclar) and polymerized for 25 minutes in the Targis Power light-curing unit.

Biodent Specimens. Metal plates for the Biodent group were fabricated differently. Small beads for retention (350 μm) were applied with an adhesive to half the wax surface before casting.

The metal specimens were cast and air-abraded with 50 μm grit aluminum oxide. The samples were steam cleaned, ultrasonically washed in distilled water for 15 minutes, and air-dried. Then Biodent was applied to the metal surface in two increments with each one cured for 20 seconds. The silicone rubber mold was removed, and the sample was cured for an extra 40 seconds from different lateral directions.

After the application of veneering materials, each specimen was embedded in an acrylic resin mold and seated in a shear testing jig (Fig 1). The overall thickness of the polymerized material layers was 3 mm. One hour after preparation, the specimens were immersed in water and incubated at 37°C for 24 hours. The specimens were loaded to failure by applying a shear force to the veneering material at the alloy interface. Shear bond strength was then measured with a universal testing machine at crosshead speed of 0.5 mm/min (Lloyd Instruments LR 30 K, Segenswonth West, Farehome, UK). The load to cause bond failure, seen as a sharp peak on the chart, was recorded for each specimen.

Shear bond strength, F/A (force per unit area), was calculated from the recorded failure loads, with an adherence area of 5 × 10 mm for all specimens.

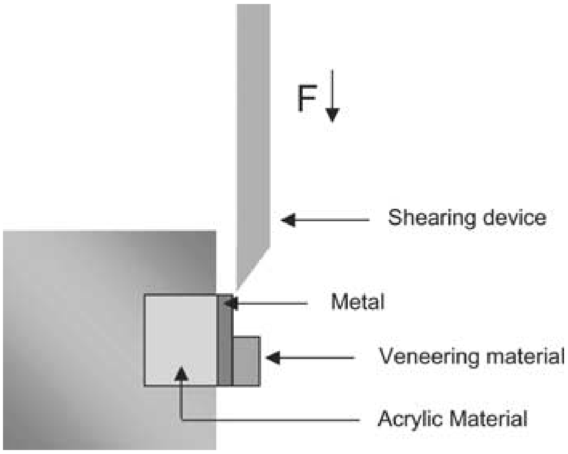

Figure 1. Test design (F = shear force).

All specimens were inspected visually for the fracture mode (cohesive, adhesive, or mixed). The fracture mode was classified as cohesive if the failure occurred within the body of the veneering material and adhesive if the failure occurred at the junction of the metal and the veneering material. The Kruskal-Wallis test was used for statistical analysis at the 5% level of significance.

Results

The means and standard deviations (SD) of shear bond strength are listed in Table 2. The strongest mean shear bond strength was obtained with samples veneered with porcelain-fused-to-metal (PFM) (34.96 ± 2.23 MPa), this was followed by Targis/Vectris (14.17 ± 1.28 MPa), Artglass (13.64 ± 1.24 MPa), and Biodent (10.56 ± 1.19 MPa).

Statistical evaluation using the Kruskal-Wallis (KW) analysis of variance was performed to determine any significant difference among veneering materials. According to statistical analysis there was a significant difference among the four groups of veneering materials ($KW = 32.26, p = 0.000$). A multiple comparison test was performed to show the difference between each pair; this revealed that no significant difference was found in the mean values between Targis and Artglass at the $p > 0.05$ level of significance. Porcelain was significantly higher and Biodent significantly lower than all other groups ($p < 0.01$). The highest values were with porcelain, and Biodent samples showed the lowest strength values. Most of the specimens tested in this study failed at the alloy-opaque interface (adhesive). In the porcelain-metal group only one fracture was observed within the opaque (cohesive); the rest were at the alloy-veneering material interface. The Targis/Vectris, Artglass, and porcelain specimens demonstrated mostly adhesive failures between the opaque composite and the metal surface. In the Biodent group all failures were cohesive in the composite (Fig 2, Table 3). As the numbers of subjects were insufficient for statistical comparison we could not make statistical analysis for failure modes.

Table 2. Mean Shear Bond Strength (MPa) of Porcelain (Vita), Targis Vectris, Artglass, and Biodent

Materials	*Shear Bond Strength (MPa)*	*SD*
Vita (PFM)	34.96[a]	2.23
Targis/Vectris	14.17[b]	1.28
Artglass	13.64[b]	1.24
Biodent	10.56[c]	1.19

Mean followed by distinct letters in the column indicate statistical difference ($p < 0.01$)

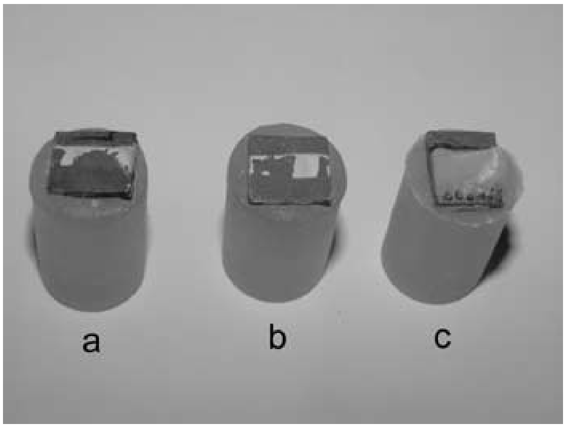

Figure 2. Adhesive bond failure between (*a*) ceramic and metal—some opaque remains adhered on alloy surface; (*b*) Artglass and metal; (*c*) cohesive bond failure within Biodent.

Discussion

This study compared the shear bond strength of different veneering materials to a Ni-Cr alloy. Bond strength refers to the force required to separate two parts, and it consists of two factors: chemical adhesion and mechanical bonding. Mechanical bonding is an anchoring effect related to surface roughness and preparations applied onto the metal surface. In the Biodent group, the mechanism responsible for bonding is the small beads applied onto the metal surface for mechanical retention. Although mechanical retention may produce high bond strength, it can also result in microleakage as well as require increased thickness of material, which, in turn, necessitates overcontouring of the restoration.[3,8,9]

Table 3. Types of Bond Failures

	Adhesive	*Cohesive*	*Mixed*
Porcelain	9	1	–
Biodent	–	10	–
Artglass	7	1	2
Targis/Vectris	6	1	3

The results of the current study have shown that the greatest mean shear bond strength is between the metal and the porcelain (34.96 MPa). The mean bonding strength values of Artglass (13.64 MPa) and Targis Vectris (14.17 MPa) were not significantly different from each other ($p > 0.05$).

The abrasion of alumina was performed to mechanically clean the surface and to increase the surface bonding area, increasing surface energy and activity of the surfaces.[6,16] Indeed, the adhesive strength of composite resins with alloys was significantly improved by sandblasting; however, sandblasting restorations, especially with 250 μm alumina (Al_2O_3), has the potential to remove significant amounts of substances and could affect the clinical adaptation of the prostheses. Unnecessary sandblasting should be avoided because it is likely to damage the margins of the restorations.[6]

The chemical bonding between the veneering agent and metal substructure can be improved with coating and primer systems. The chemical attachment of an opaque layer to the metal surface limited microleakage at the resin-metal interface that occurred because of polymerization shrinkage and mismatch of the coefficient of thermal expansion between the composite and the metal.[9,17] The new highly filled indirect resins such as Artglass and Targis have become alternatives to porcelain as veneering material. They are as esthetically pleasing as porcelain, and they bond well to metal when used as veneering material. These materials contain at least 1.55 fine particle-size filters, commonly a silicate glass embedded in a resin matrix.[5] Little information is available on the comparative strength of these highly filled resins when used as veneering material.

As Artglass and Targis/Vectris are composite resin materials with improved mechanical properties due to new filling concepts and changes in the matrix, they undergo some plastic deformation before failure, whereas ceramics do not, due to their brittleness.[2] The mode of failure shifted from cohesive to adhesive, which can be explained by the particular composite tested (Artglass, Kulzer).[18] The reason for adhesive failure may be attributed to the strength of these materials in their structure. According to Matsumura et al, a shear bond strength greater than 10 MPa will be satisfactory for veneering materials.[10] All materials showed adhesive failure, except the Biodent group. In the Biodent group all failures were cohesive in the composite. This can be explained by insufficient strength of the mechanical bonding to the metal surface.

The results indicate that for extending the service period of resin composite the development of a chemical resin-to-metal bonding should be considered, which will also reduce the need for mechanical retention on metal frameworks.

Conclusions

The following conclusions were drawn from this investigation:

1. The bond of conventional feldspathic PFM was significantly higher than that of resin-to-metal bonding systems.
2. Artglass and Targis-Vectris had lower shear bond strength values than the PFM group; however, they were higher than the Biodent group.
3. Biodent had the lowest shear bond strength values of the four tested materials.
4. The majority of the failure modes was adhesive at the junction of the metal and opaque or resin.

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