Force Needed to Separate Acrylic Resin from Primed and Unprimed Frameworks of Different Designs

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Abstract

Purpose: Poor mechanical and chemical bondings at the interface between a framework and denture base resin have been responsible for many removable partial denture failures. This study tested the force necessary to separate acrylic resin bases from test frameworks using different acrylic retention designs (smooth metal plate, metal plate with bead retention, lattice retention, and mesh retention). The force needed to separate acrylic resin from primed test frameworks was also measured.
Materials and Methods: Eighty chromium-cobalt test frameworks were fabricated using preformed wax patterns and cast according to manufacturer's instructions. Half the specimens were primed prior to acrylic processing. The same base acrylic was used for all specimens. Separation forces that fractured acrylic resin from test frameworks were generated by a universal testing machine at a crosshead speed of 25 mm/min. Loads at failure and types of failure were recorded. Data were analyzed using ANOVA.
Results: The mean separation force of acrylic resin from unprimed retention designs was highest for the metal plate with beads (3.1 kN), followed by mesh (2.8 kN) and lattice (2.1 kN), and lowest (0.1 kN) for the smooth metal plate. The mean separation force for primed acrylic retention designs was highest for the metal plate with beads (4.2 kN), followed by mesh (3.4 kN) and smooth metal plate (3.0 kN), and lowest for lattice retention (2.6 kN). Bond failure occurred both adhesively at the interface between metal and acrylic resin and cohesively within the acrylic resin. Cohesive bond failure increased when specimens were primed. The rate of cohesive bond failure remained the same for primed mesh retention specimens.
Conclusions: Significantly increased force was necessary to separate the acrylic from each design of primed test specimens compared with unprimed specimens of the same design. The primed metal plate with beads exhibited significantly greater separation force than the other three designs. Primed mesh had significantly greater separation force values than primed lattice and smooth metal plate. Primed lattice was significantly less retentive than the other three primed designs. Except for the retentive mesh specimens, there was higher occurrence of cohesive failures in the acrylic resin when the frameworks were primed.

The removable partial denture (RPD) literature has offered little guidance as to the most effective metal/acrylic resin retention design. Boucher and Renner[1] stated that the three most commonly used acrylic retention designs were open lattice, preformed mesh, and a metal base with bead retention. They endorsed the lattice design; however, it had high susceptibility to permanent deformation. Brudvik[2] reported that nonrelieved retention beads were superior because they required less interarch space. Brown et al[3] recommended mesh retention because lattice retention was more susceptible to deformation and metal failure.

Dunny and King[4] tested nine acrylic retention designs for an anterior edentulous space. They suggested that the strength of acrylic resin retention was directly proportional to the diameter of the spaces in the metal grid. The large open-loop or bar network designs offered the strongest retention for the base, while bead retention and labial projections of the framework did not provide strong attachment.

The retentive strength of acrylic resin to acid-etched denture frameworks has been reported as an alternative to mechanical retention.[5-7] Electrochemical etching improved bond strength and avoided overcontouring of prostheses; however, it was technique sensitive, time-consuming, and did not work well with precious metal alloys.

Zurasky and Duke[8] compared the retentive bond strength of acid-etched base metal to acrylic resin with that of retentive beads. They found that the bond with the acid-etched base was 3.5 times greater than that of bead retention.

The volumetric shrinkage of acrylic resin and the different coefficients of thermal expansion of metal and acrylic resin have allowed microleakage at the interface.[9] RPDs have been subject to microleakage as a result of the thermal effects of hot and cold beverages.[10] Chemical bonding reduced the gap at the resin/metal interface, minimizing microleakage.[11]

Various metal surface treatments have been used to provide a stronger metal/resin bond. Chemical bonding systems were intended to decrease or eliminate the need for mechanical retention.[12] The intent was to reduce impingement of the metal framework on the acrylic resin matrix, thereby increasing the strength of acrylic resin.[13] Kourtis[14] classified chemical bonding systems into three main groups according to their mechanisms of chemical adhesion to metal: silicate layer/silane coupling agents, active acrylate monomers/polyfluormethacrylate bonding agents, and tin/oxide layer.

The Silicoater (Heraeus–Kulzer) system developed by Tiller et al in 1984 was the earliest reported chemical retentive system. An intermediate layer containing silicone dioxide (SiO_2) on the metal surface provided sufficient bonding of acrylic resin via a silane bonding agent.[15] Several studies have demonstrated that the bond strength of silica-coated metal was significantly higher than that of sandblasted and electro-etched metal;[11,16-21] however, expensive equipment, time constraints, and technique sensitivity were among the disadvantages of the process.[22] Functional methacrylate monomers have been synthesized and used successfully as primers for bonding acrylic resin to dental alloys.

MEPS (thiophosphoric methacrylate) is a monomer containing a sulfur atom in the thiophosphoric part of the molecule. This sulfur molecule has affinity for precious metal alloys. Watanabe et al[23] reported that MEPS effectively enhanced the adhesive bond between type IV gold alloy and 4-META/MMA-TBB (4-methacryloyloxyethyl trimellitate anhydride/methyl methacrylate-tri-n-butylborane) resin. Taira et al[24] suggested that the strong bond of MEPS to titanium alloy was due to a hydrophobic phosphate derivative group in the MEPS monomers. They also found that the thin oxide film produced on the surface of titanium alloy was strongly adherent to 4-META in their bonding study of acidic primers and TBB resin.[25]

Yoshida et al[26] suggested that functional monomers had an affinity for the oxide layer formed on chromium-cobalt casting surfaces. All adhesive primers tested increased the shear bond strength of acrylic resin bonded to the alloy surfaces.

NaBadalung and Powers[27] studied the effectiveness of adhesive systems for chromium-cobalt RPD alloys. They compared two surface pretreatments (sandblasted, sandblast-electrochemically etched) and three adhesive primers (Lee Metal Primer, Acrylic Solder, CR Inlay Cement). The tensile bond strength of primed specimens showed significantly higher bond strengths than unprimed specimens. Thermocycling for 1000 cycles lowered the bond strength of all primed specimens.

Ohkubo et al[28] compared the shear bond strength of denture base resin (polymethyl methacrylate) to cast titanium and cobalt-chromium, using five metal primers (Metal Primer II, Cesead Opaque primer, Meta Base, experimental primer, Siloc bonding system). They found that primed specimens showed significantly higher shear bond strength than unprimed controls. Shear bond strength decreased after thermocycling.

Tanaka et al[29,30] first developed 4-META, and recommended it for veneer crowns, resin-bonded retainers, and porcelain repair. They suggested that it was easy to apply, minimally technique sensitive, and required only basic equipment.[29]

A powder-liquid PMMA/MMA system including 5% 4-META in the monomer demonstrated increased bond strength to some metal alloys over conventional denture base resins.[31] The highest bond strength was observed between the denture base resin containing 4-META and a flat metal plate, the lowest between denture base resin containing 4-META and a mesh retentive design.[34]

Three different retentive designs (mesh, ring-shaped, flat planes) were processed using conventional denture base acrylic resin and 4-META adhesive acrylic resin. Following shear testing, the highest bond strength was observed between the 4-META adhesive acrylic resin and the flat plate design. Canay et al[35] suggested that no mechanical retention was needed if the 4-META acrylic resin was used for relining. Barclay and Williams[36] concluded that the highest tensile bond strength was recorded between silicoated chromium-cobalt alloy and 4-META acrylic resin.

An adequate mechanical retention design for acrylic resin in an RPD framework design has usually been empirical due to lack of scientific research. This investigation evaluated the separation force necessary to fracture acrylic resin from frameworks with different retention designs and also compared the influence of metal primer on the acrylic retention.

Materials and methods

Eighty chromium-cobalt alloy (Wironium, Bego, Bremen, Germany) frameworks with four acrylic retention designs were constructed to fit a brass metal master cast: (Fig 1)

- Smooth metal plate
- Metal plate with bead retention
- Mesh retention
- Lattice retention.

The brass metal master cast was constructed using a random maxillary cast with all incisors missing.[4] Undercuts were blocked out, and all remaining teeth distal to the canines were removed. Cingulum rests were prepared in both cuspids. A step

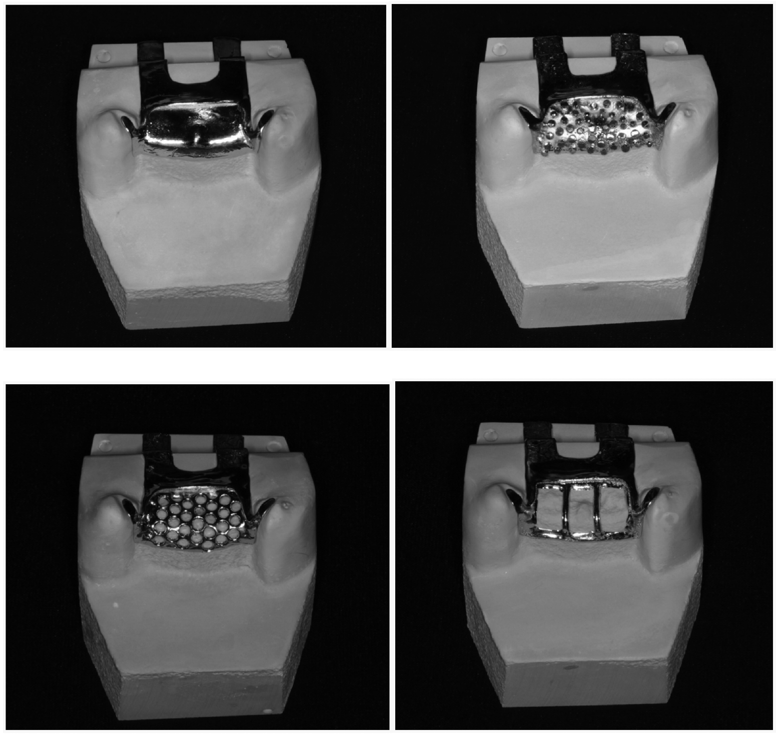

Figure 1 Framework designs (upper left: smooth metal plate; upper right: metal plate with bead retention; lower left: mesh retention; lower right: lattice retention).

behind the abutments was machined to allow space for a bar to retain the test frameworks (Fig 2). The brass metal cast was positioned in a jig 45° to the table top. This angle was used to simulate the clinical position of the maxillary teeth.[4]

A poly(vinyl siloxane) (Aquasil, Dentsply International, York, PA) impression was made of the metal master cast. The impression was poured with Type IV stone (Resin Rock, Whip Mix Corp, Louisville, KY). A two-component addition-cured silicone (Wirosil, Bego) system was used to duplicate the master cast. After hardening under pressure for 30 minutes, the baseplate was removed, and silicone that had flowed under the master cast was trimmed. The master cast was then separated from the silicone mold (Wirosil). A wetting agent (Aurofilm, Bego) was sprayed on the mold and dried with compressed air for 30 seconds.

The refractory casts were poured with a phosphate-bonded investment material (80% BegoSol and 20% distilled water) (Wiroplus® S, Bego). The investment was manually mixed

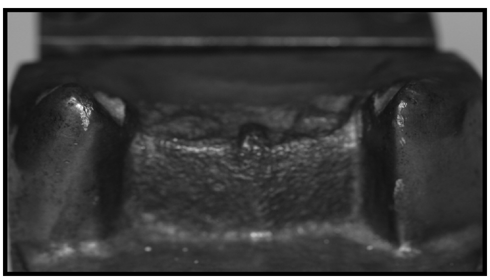

Figure 2 Metal master cast.

for 15 seconds, and then vacuum mixed in the Easy Mix unit (BEGO) for 60 seconds. It was then poured into the duplicating mold under vibration. The investment cast was removed from the silicone mold after 40 minutes.

The investment casts were dried at 70°C for 10 minutes in a preheated furnace, and then evenly coated in a dipping hardener (Durol, BEGO) to improve adhesion of preformed wax patterns. Framework designs were transferred to the investment casts, and preformed wax patterns (BEGO) were adapted. A 3.5-mm diameter universal sprue former was positioned in the center of the cast and luted to all sprues.

The wax patterns were invested with a vacuum-mixed, phosphate-bonded investment according to the manufacturer's instructions (Wiroplus® S 30% BegoSol) and 70% distilled water. The invested patterns were allowed to set for the first 10 minutes in a pressure compaction unit. They were recovered from the mold formers and allowed to set for an additional 20 minutes before preheating. The patterns were then placed in a preheated furnace (Nabertherm, Bego) set to reach 250°C over 30–60 minutes and then to 950–1000°C over the next 30–60 minutes. A microprocessor-controlled HF vacuum pressure casting machine (Nautilus® MC plus, Bego) was used to melt and cast the alloy (63% Cr, 31% Co, 3% Mo, 0.25% C, Misc. Si, Mn, N; Wironium Plus). After casting, the molds were air-cooled and deflasked.

All test frameworks were porosity free, complete castings. They were fitted to the master cast followed by finishing and polishing. Sprues were removed with separating discs (Bego). Finishing was carried out with perforated discs and #6 and 7 diamond grinding stones. Sandblasting (Duostar Combination blaster, Bego) was accomplished using a grain size of

250 μm under a working pressure of 4–6 bar. The frameworks were steamed cleaned and air-dried. All frameworks were electropolished (Electropol SL, BEGO) for 6 minutes. Final polishing was carried out using rubber polishing wheels, tips, and polishing compounds (Wiroflex Gummi Polierscheiben/Spitzen, BEGO).

Metal treatment

The eighty test frameworks were divided into two groups:
Control group (No Primer)—40 specimens

- Smooth metal plate (10)
- Metal plate with bead retention (10)
- Mesh retention (10)
- Lattice retention (10)

Metal Primer II Groups—40 specimens

- Smooth metal plate (10)
- Metal plate with bead retention (10)
- Mesh retention (10)
- Lattice retention (10)

Metal Primer II groups

Forty test frameworks had Metal Primer II: MEPS (GC Corporation, Tokyo, Japan) applied according to the manufacturer's instructions. After complete wax removal, the bonding surfaces were blasted with alumina and then cleaned with compressed air followed by steam. After the surfaces were allowed to dry completely, a thin layer of Metal Primer II was applied to the bonding surface. Denture base acrylic resin was packed and cured immediately thereafter.

Processing the resin

Maxillary anterior denture teeth (Ivoclar Vivadent, Inc, Amherst, NY) were set on the framework, and a stone matrix was fabricated to duplicate the same thickness of the acrylic and teeth on all test frameworks. Frameworks were invested in flasks using lab plaster (Modern Materials, Heraeus Kulzer, Armonk, NY) with a powder/liquid ratio of a 100 g/47 ml. After wax elimination, forty frameworks were processed conventionally using Lucitone 199 acrylic resin (Dentsply International). Remaining frameworks were treated with Metal Primer II and similarly processed using Lucitone 199 acrylic resin. A two-stage curing unit (Teledyne Hanau, New York, NY) was set for a long cure (stage one for 8 hours at 160° F, stage two for 9 hours at 230° F). The specimens were finally deflasked and finished.

The separating forces that separated the acrylic resin from the test frameworks were recorded in kN using a universal testing machine (Instron Corp, Canton, MA) at crosshead speed of 25 mm/min. The loads and type of failure were recorded. Types of failure were classified as adhesive if the failure occurred at the metal/resin interface or as cohesive if the failure occurred within the acrylic resin.

Table 1 Separation force (kN) for four designs with and without primer

Design	Primer	No primer
Metal plate—beads	4.2 (0.4)	3.1 (0.7)
Mesh retention	3.4 (0.3)	2.8 (0.2)
Metal plate—smooth	3.0 (0.4)	0.1 (0.2)
Lattice retention	2.6 (0.3)	2.1 (0.4)

Means with standard deviations in parentheses. Fisher's PLSD intervals for comparisons of means among designs and between treatments were 0.3 and 0.2 kN, respectively. Comparisons of means among designs and between treatments were all different statistically ($p < 0.05$).

Statistics

Means and standard deviations of separation forces were calculated and recorded. Data were analyzed statistically using two-way ANOVA and comparisons of means with Fisher's PLSD test at the 0.05 level of significance.

Results

Means and standard deviations of the separation force (kN) for four acrylic retention design frameworks treated with and without primer are listed in Table 1. Fisher's PLSD (protected least significant difference) intervals ($p < 0.05$) for comparisons of means among the four designs and between primed and unprimed treatments were 0.3 and 0.2 kN, respectively.

The mean separation force for acrylic retention frameworks without primer was highest for the metal plate with bead retention (3.1 kN), followed by mesh retention (2.8 kN) and lattice retention (2.1 kN). The smooth metal plate yielded the lowest separation force (0.1 kN).

Greater mean separation forces were observed in this study where frameworks were chemically bonded to acrylic resin. The mean separation force for primed frameworks was highest for the metal plate with bead retention (4.2 kN), followed by mesh retention (3.4 kN) and smooth metal plate (3.0 kN). Lattice retention showed the lowest mean separation force (2.6 kN).

The smooth metal plate group failed 100% adhesively at the interface of metal and acrylic resin, but the metal plate with bead retention and mesh retention failed 90% cohesively in the acrylic resin. The lattice retention group failed 50% cohesively in the acrylic resin.

The smooth, primed metal plate group showed 40% cohesive failure in acrylic, followed by the primed lattice group (70% cohesive failure) and primed mesh group (90% cohesive failure). One hundred percent cohesive failure in acrylic was found in the primed metal plate with bead retention (Fig 3).

Discussion

Methods for bonding acrylic resin to metal alloys have been categorized as mechanical, chemical, or a combination of both. Poor bonding of acrylic resin to metal frameworks has often been responsible for prosthesis failure. Improvement of acrylic resin to metal bond strength could enhance clinical success.

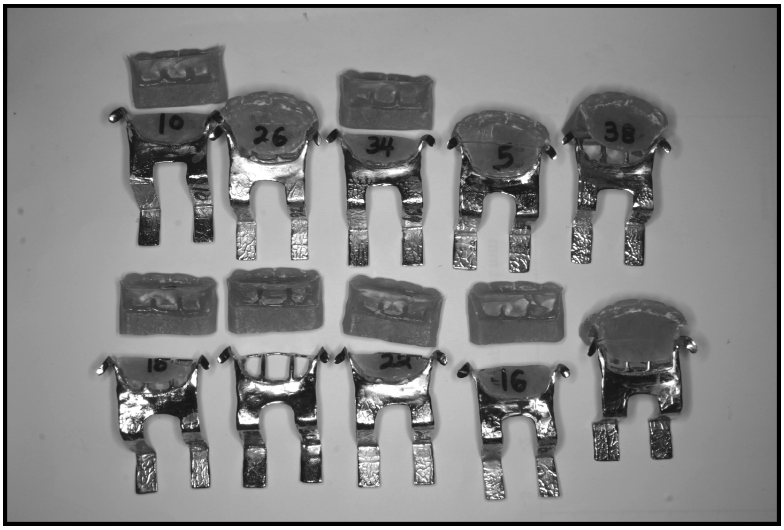

Figure 3 Typical bond failures.

The metal plate with bead retention showed significantly higher mean separation forces compared with a smooth metal plate and lattice retention. This was inconsistent with a previous report by Dunny and King[4] who noted that bead retention did not offer strong retention for acrylic resin. They suggested that the open lattice type of design provided the strongest retention due to the bulk of acrylic resin. The metal plate with bead retention in this study proved to be effective in mechanically bonding acrylic resin to cast metal frameworks. Because the acrylic needed to flow evenly around the bead undercuts, the size and number of beads were important.

Mesh retention showed significantly higher mean separation forces than the lattice and smooth metal plate designs. This was consistent with Brown et al[3] and Canay et al,[33] who demonstrated that retentive mesh was more effective in retaining acrylic resin than the lattice design.

There was one detectable metal fracture and instance of deformation found in this study. Each occurred with the primed lattice retention. The possibility of metal failure and deformation with the lattice design has been discussed by other authors (Brown et al,[3] Jacobson et al,[31] and Canay et al[33]), who cautioned against its use due to its high susceptibility for permanent deformation.

The metal/resin interface has often been subject to microleakage of oral fluids along finish lines due to differences in the coefficient of thermal expansion between the two materials.[35] Microleakage results from a breakdown of the interface, leading to discoloration, deterioration of the acrylic resin, and creation of a reservoir for oral debris and microorganisms. Incomplete fracture or total separation of the resin can occur. Significant research has focused on an improved bond (between acrylic resin and metal), capable of withstanding occlusal forces and enduring the oral environment.

Combining mechanical and chemical bonding significantly increased mean separation forces in this study. Specimens treated with Metal Primer II showed a significantly higher mean separation force than unprimed specimens. Metal Primer II has incorporated a special monomer (MEPS: thiophosphoric methacrylate) containing a sulfur atom in the thiophosphoric part of the molecule. Functional monomers have an affinity for the layer of chromium oxide that forms on a chromium cobalt alloy surface.[26] Several studies have shown the effectiveness of the functional methacrylate monomers.[23-28,36,37]

Smooth primed metal plates displayed significantly higher mean separation forces than those of primed lattice retention. The strength of the chemical bond appeared to be proportionally related to the metal surface area. Primed metal plate designs provided high mean separation forces but could not be relined.

Cohesive bond failure in acrylic resin was observed more often among primed specimens, with the exception of mesh retentive specimens. Canay et al[33] also observed a cohesive shear bond fracture in the group treated with 4-META and adhesive shear bond fracture in the untreated group.

Conclusions

Under the conditions of this study, the following conclusions were drawn. Significantly increased force was necessary to separate the acrylic from each design of primed test specimens compared with unprimed specimens of the same design. The primed metal plate with beads exhibited significantly greater separation force than the other three designs. Primed mesh had significantly greater separation force values than primed lattice and smooth metal plate. Primed lattice was significantly less retentive than the other three primed designs. Except for the retentive mesh specimens, there was higher occurrence of cohesive failures in the acrylic resin when the frameworks were primed.

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