Porcelain repair - Influence of different systems and surface treatments on resin bond strength

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PURPOSE. The purpose of this study was to evaluate the bond strength of composite resin on the fracture surface of metal-ceramic depending on the repair systems and surface roughening methods. **MATERIALS AND METHODS.** A total of 30 disk specimens were fabricated, 15 of each were made from feldspathic porcelain and nickel-chromium base metal alloy. Each substrate was divided into three groups according to the repair method: a) application of repair system I (Intraoral Repair Kit) with diamond bur roughening (Group DP and DM), b) application of repair system I with airborne-particle abrasion (Group SP and SM), and c) application of repair system II (CoJet Intraoral Repair System, Group CP and CM). All specimens were thermocycled, and the shear bond strength was measured. The data were analyzed using the Kruskal-Wallis analysis and the Mann-Whitney test with a significance level of 0.05. **RESULTS.** For the porcelain specimens, group SP showed the highest shear bond strength (25.85 ± 3.51 MPa) and group DP and CP were not significantly different. In metal specimens, group CM showed superior values of bond strength (13.81 ± 3.45 MPa) compared to groups DM or SM. **CONCLUSION.** Airborne-particle abrasion and application of repair system I can be recommended in the case of a fracture localized to the porcelain. If the fracture extends to metal surface, the repair system II is worthy of consideration. ***[J Adv Prosthodont 2015;7:343-8]***

KEY WORDS: Porcelain repair; Composite resin; Shear bond strength; Tribochemical silica coating

INTRODUCTION

Porcelain-fused-to-metal crowns have been used as predictable materials since the 1960s, owing to their mechanical strength and low cost.[1,2] However, porcelain veneer failure has been reported as the major cause for the replacement of metal-ceramic restorations.[3,4] The fracture of veneering porcelain may result from trauma, improper metal framework design, incompatibility between the thermal expansion coefficient of the porcelain and core, inadequate tooth preparation, inadequate occlusal adjustment, and intraceramic defects.[5,6] The rate of failure caused by porcelain fracture is reported in the literature to be approximately 2-16%,[4,7-9] and the majority of failures (65%) are observed in the anterior region, and mainly in the maxilla (75%), predominantly at the labial surface.[10] Also, failure may often occur in the anterior regions, presenting a serious aesthetic problem. The immediate replacement of failed complex prostheses is often impossible though, as it requires additional time, effort, and expense. In this situation, repair is a suitable method to rehabilitate the contour and color of fractured restorations. Such repair demands durable bonding, even though it is not a permanent treatment.

Intraoral repair using a Bis-GMA composite light-cured resin can be an alternative method that offers great benefits due to its superior aesthetics, color stability, and ease of application.[11] Various techniques for the preparation of exposed surfaces have also been introduced to improve the

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bonding qualities between metal or porcelain substrates and resin composites. Tribochemical silica coating is an effective surface treatment regardless of whether the fracture takes place in metal or porcelain, or is a combined exposure.[1,12-14] Hydrofluoric acid etching followed by the application of a silane coupling agent also promotes good results in the preparation of a ceramic surface, and it is commonly used in clinics due to its simplicity.[15-18] Before the application of hydrofluoric acid, the exposed surface can be roughened by a diamond bur or by sandblasting with aluminum oxide, both of which can affect the bond strength. Several researchers reported that mechanical roughening by both a diamond bur and sandblaster was effective for porcelain repair.[19,20] The best results were achieved with a bur by Leibrock and colleagues[3] and with sandblasting by Tulunoglu and Beydemir.[21] In many studies, however, the comparison of bonding qualities with different roughening methods was performed using different resin composite repair systems. For this reason, a comparison based upon the use of the same repair system is needed in order to confirm the differences in roughening procedures.

The purpose of this study was to evaluate the bond strength of two porcelain repair systems for the metal and porcelain surfaces: the repair system I (Intraoral Repair Kit, Bisco Inc., Schaumburg, IL, USA) and the repair system II (CoJet Intraoral Repair System, 3M ESPE AG, Seefeld, Germany), and the differences in bond strength obtained by two different surface treatments with identical repair system: 1) roughening with diamond bur and 2) airborne-particle abrasion. The null hypothesis tested was that, regardless of the repair systems and surface treatments, the bond strength between the core surface (metal and porcelain) and resin composite veneer would not be different among the groups.

MATERIALS AND METHODS

All the components of the resin composite repair systems and their chemical compositions used in this study were listed in Table 1. Fifteen disks (1.0 mm thickness × 8.0 mm diameter) were fabricated with feldspathic porcelain (Vintage MP, Shofu Inc., Kyoto, Japan) according to the manufacturer's instructions. Another fifteen specimens were made of a nickel-chromium alloy (Bellabond Plus, BEGO, Bremen, Germany) with identical dimensions with porcelain disks. All disks were then placed into the stainless steel molds and fixed with an auto-polymerizing poly-methyl methacrylate resin (Ortho-jet, Lang, Wheeling, IL, USA). The testing surfaces were protected with cellulose tape. After polymerization, the resin cylinders were separated from the molds, and the test surfaces were smoothened with 220-grit abrasive paper and carefully polished (Sof-Lex Extra Thin, 3M ESPE AG, Seefeld, Germany). The specimens were cleaned in an ultrasonic bath with distilled water for 5 minutes.

The specimens, either feldspathic porcelain (P) or nickel-chromium metal alloy substrates (M), were divided into three groups according to the applied repair systems and surface treatments: 1) application of repair system I (Intraoral Repair Kit, Bisco Inc., Schaumburg, IL, USA) with surface roughening with diamond bur (Group DP and DM), 2) application of repair system I with airborne-particle abrasion (Group SP and SM), and 3) application of repair system II (CoJet Intraoral Repair System, 3M ESPE AG, Seefeld, Germany) (Group CP and CM). For the group DP, the porcelain surfaces were roughened with a diamond bur and 4% hydrofluoric acid gel (Porcelain Etchant, Bisco Inc., Schaumburg, IL, USA) was applied for 5 minutes. A silane coupling agent (Porcelain Primer, Bisco Inc., Schaumburg,

Table 1. Information of the materials used in the study

	Component	Chemical composition	Lot No.
Intraoral Repair Kit (Bisco Inc., USA)	Porcelain Etchant	4% Hydrofluoric acid	1300002868
	Porcelain Primer	Silane with ethanol and acetone	1300005107
	Opaquer Catalyst	Bis-GMA, benzoyl peroxide	1000010727
	Opaquer Base Universal	Bis-GMA, urethane dimethacrylate	1000010727
Metal primer Adhesive (Bisco)	Z-Prime Plus	Biphenyl dimethacrylate, HEMA, ethanol	1000003112
	ONE-STEP Plus	Biphenyl dimethacrylate with acetone, HEMA	1400006379
Composite (Bisco)	AEITE All-Purpose Body	Ethoxylated Bis-GMA, TEGDMA	1300003757
CoJet Sand system (3M ESPE, Germany)	CoJet Sand	30 μm aluminum oxide modified silica	439147
	ESPE-Sil	3-methacryloxypropyltrimethoxysilane with ethyl alcohol	225505
Opaque (3M ESPE)	Sinfony opaque liquid	Dicyclopentyldimethylene diacrylate, MMA	159673
	Sinfony opaque powder	Silane treated quartz, titanium dioxide	
Adhesive (3M ESPE)	Adper Single Bond 2	Bisphenol diglycidyl ether dimethacrylate 2-hydroxyehtyl methacrylate with ethyl alcohol	N407020
Composite (3M ESPE)	Filtek Z250	Bis-GMA, TEGDMA	N528688

IL, USA) was applied onto the each treated surface, which was allowed to react for 30 seconds, and air-dried. An adhesive (ONE-STEP Plus, Bisco Inc., Schaumburg, IL, USA) was subsequently applied, air-thinned and photo-polymerized for 10 seconds with a visible light curing unit (Elipar FreeLight2, 3M ESPE AG, Seefeld, Germany). After a glass matrix with a 6.0 mm diameter was placed on the specimens in order to obtain an equal bonding area, a hybrid resin composite (AELITE All-Purpose Body, Bisco Inc., Schaumburg, IL, USA) was applied with a thickness of approximately 1.5 mm, and cured for 20 seconds. After the matrix was removed, an additional 20 seconds of visible light was applied. For the metal specimens, the surfaces of DM group specimens were roughened with a diamond bur. A metal primer (Z-PRIME Plus) was brushed and air-thinned for 5 seconds according to the manufacturer's instruction. An adhesive (ONE-STEP Plus) was then applied, air-thinned and photo-polymerized for 10 seconds with a visible light curing unit (Elipar FreeLight2). The mixture of the catalyst and base (Opaquer Catalyst and Opaquer Base Universal, Bisco Inc., Schaumburg, IL, USA) was applied to the prepared surface and photo-polymerized for 10 seconds. A hybrid resin composite (AELITE All-Purpose Body) was applied in the same method as previous procedures with the porcelain substrates. For the group SP and SM, the test surfaces were subjected to airborne-particle abrasion (Airsonic Mini Sandblaster, Hager & Werken, Duisburg, Germany) with 50-μm aluminum oxide particles (Cobra, Renfert, Hilzingen, Germany) from a distance of 10 mm at a pressure of 0.3 MPa. The subsequent procedures for the application of porcelain repair system on porcelain and metal disks were identical as those used in the group DP and DM, respectively. For the group CP, 30-μm silica-coated alumina particles (CoJet Sand, 3M ESPE AG, Seefeld, Germany) were blasted from a distance of 10 mm at a pressure of 0.3 MPa. After blasting, the porcelain substrates were coated with γ-MPS silane (ESPE Sil, 3M ESPE AG, Seefeld, Germany) and then air-dried. For the group CM, a primer (Z-PRIME Plus) was applied and dried for 5 seconds on the metal substrate. A mixture of Sinfony opaque and catalyst (3M ESPE AG, Seefeld, Germany) was subsequently applied and photo-polymerized for 10 seconds according to the manufacturer's instruction. For both core specimens, an adhesive (Adper Single Bond 2 Adhesive, 3M ESPE AG, Seefeld, Germany) was applied, air-thinned and photo-polymerized for 10 seconds. The resin composite (Filtek Z250, 3M ESPE AG, Seefeld, Germany) was layered on the test surface of each substrate with a thickness of approximately 1.5 mm using customized matrix and cured using the same protocol as with the group DP. All specimens were then stored in 37°C distilled water for 15 hours and thermocycled between 5°C and 55°C for 1000 cycles with a 30 seconds-dwell time. After cycling, they were additionally stored in 37°C distilled water for 192 hours before being subjected to a shear load. A universal testing machine (Instron 3345, Instron Corp., Norwood, IL, USA) with a 10-kN load cell and a 0.5-mm/min crosshead speed, a flat-end apparatus was used to direct parallel shearing forces as close as possible to the resin/substrate interface (Fig. 1). The shear load in newtons at the point of failure was noted, and force was calculated in MPa. The mode of failure was recorded as being adhesive (failure at the substrate-resin interface), cohesive (failure within the substrate), and mixed (adhesive and cohesive).

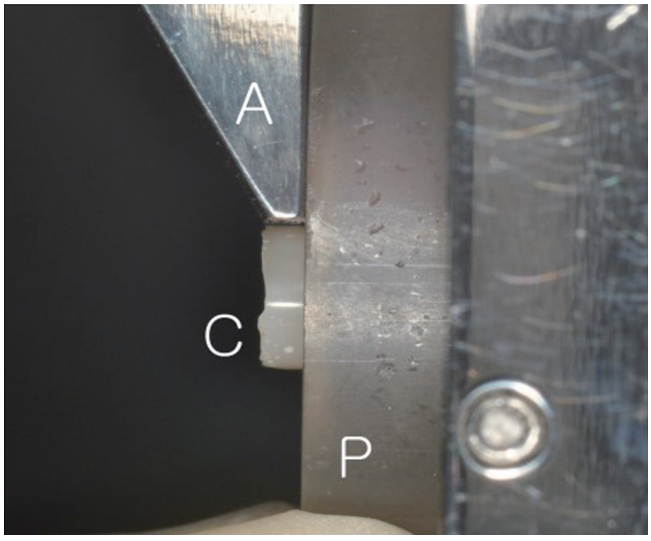

Fig. 1. Specimen of resin composite bonded to substrate aligned in universal testing machine for measurement of shear bond strength (A: apparatus of shear load, C: resin composite, P: poly-methyl methacrylate mold with porcelain or metal substrates).

All data (MPa) were analyzed using a statistical software package (PASW Statistics 18, IBM SPSS, Chicago, IL, USA) that employs the Kruskal-Wallis analysis and the Bonferroni post-hoc test for the multiple comparison between the groups with identical core surfaces to determine the effect of repair system on the adhesion to the resin composites. Additional statistical analyses for the influence of the substrates on the resin bonding qualities according to various repair methods were performed with Mann-Whitney test. Statistical significance was defined at a 95% level.

RESULTS

The mean shear bond strengths of porcelain and metal specimens were listed in Table 2. On the porcelain surface, the application of airborne-particle abrasion with repair system I (Intraoral Repair Kit) significantly improved the core-resin composite bonding compared to other repair methods ($P < .05$). The repair system I applied with diamond bur roughening and the repair system II (CoJet Intraoral Repair System) were not significantly different in core-veneer bond strength. On the metal surface, application of the repair system II was significantly beneficial to

Table 2. Mean shear bond strength values and statistical analysis results of the specimens tested in the study

Type of core material	Group	Mean (MPa)	SD
Porcelain	DP (Repair system I)	16.28^{Aa}	4.50
	SP (Repair system I)	25.85^{Ba}	3.51
	CP (Repair system II)	16.23^{Ac}	2.16
Metal (Ni-Cr alloy)	DM (Repair system I)	3.12^{Cb}	1.16
	SM (Repair system I)	6.56^{Cb}	2.88
	CM (Repair system II)	13.81^{Dc}	3.45

Values followed by identical uppercase letters present no statistical differences between groups with identical core materials. Lowercase letters with the same subscript show no significant differences between groups with identical repair methods. DP and DM group: porcelain and metal specimens treated with repair system I (Intraoral Repair Kit) after diamond bur roughening, respectively; SP and SM group: porcelain and metal specimens treated with repair system I (Intraoral Repair Kit) after airborne-particle abrasion; CP and CM group: porcelain and metal specimens treated with repair system II (CoJet Intraoal Repair system).

the core-resin composite bonding than other methods using repair system I ($P < .05$). Regardless of the surface roughening methods, the repair system I showed significantly higher bond strength of resin composite to the porcelain substrate than to the metal core ($P < .05$). On the contrary, the repair system II showed similar bonding quality for both metal and porcelain core to the resin composite ($P > .05$).

Values followed by identical uppercase letters present no statistical differences between groups with identical core materials. Lowercase letters with the same subscript show no significant differences between groups with identical repair methods. DP and DM group: porcelain and metal specimens treated with repair system I (Intraoral Repair Kit) after diamond bur roughening, respectively; SP and SM group: porcelain and metal specimens treated with repair system I (Intraoral Repair Kit) after airborne-particle abrasion; CP and CM group: porcelain and metal specimens treated with repair system II (CoJet Intraoal Repair system).

In the porcelain specimens, mixed type of failure was present 100% in the DP group, 80% in the SP group, and 60% in the CP group. In the metal specimens, adhesive failure occurred when the repair system I was applied after diamond bur roughening. No opaque resin remained on the specimens of the DM group. The mixed failure appeared both predominantly in the groups SM and CM.

DISCUSSION

In this study, one repair system with tribochemical silica-coating (CoJet Intraoral Repair System) was compared with another repair system (Intraoral Repair Kit) with two different surface roughening treatments recommended by the manufacturer. Based on the results, the null hypothesis was rejected since the bond strength of substrate to resin composite was significantly different among the groups with different repair methods. It could be inferred that using the Intraoral Repair Kit with airborne-particle abrasion was helpful in repairing fractured porcelain surface, while CoJet Repair System was beneficial to restore exposed metal surface with resin composite. Each group of metal specimens displayed a unique failure mode in response to different repair methods. The metal specimens treated by the repair system I (Intraoral Repair Kit) after diamond bur roughening displayed adhesive failure, and also showed low bond strength. In the specimens roughened by sandblasting, the opaque porcelain was often partially detached. Also, a greater part of the opaque porcelain failed in metal specimens treated by the repair system II (CoJet Repair System) than failed using the repair system I. The failure mode of the metal specimens tends to reflect the core-resin bond strength values, which demonstrated a stronger bond between the exposed metal surface and resin composite in the groups with repair system II than in the groups with repair system I.

Various techniques such as acid etching, sandblasting, silanization, and application of metal primer have been introduced for the repair of fractured metal-ceramic restorations. Acid etching of feldspathic porcelain creates micromechanical undercuts that have a decisive effect for better adhesion.[2,22] Many studies have reported that a combination of micromechanical roughness and silane application to the porcelain creates durable bonding.[15-18] Silane is a dual functional monomer that consists of a silanol group that reacts with the ceramic surface, and it contains a methacrylate group that co-polymerizes with the resin matrix of the composite.[2] Silane coupling agents are known to enhance the wettability of glass substrates by resin composites and are also known to increase the mechanical and chemical bonding of resin composite to ceramics.[23] The alloy primer or composite containing diphosphate monomer (MDP), which has a phosphate ester group to bond directly to metal oxides, has been assessed as having superior bonding durability to base metal alloy.[24,25] In addition, a tribochemical silica coating was also investigated that could provide increased bond strength even to metal, and with less influence upon the surface materials.[1,12-14]

To the contrary of our findings, Ozcan and coworkers[26]

reported that the 'Intraoral Repair Kit' revealed significantly lower bond strength values than those of the 'CoJet Repair System' for surface of feldspathic porcelain after thermocycling, which were also tested in this study. Surface roughening with diamond bur or particle abrasion before using the porcelain repair system, omitted in the previous study, could be the reason of the difference between the results of the studies.[27] The application of 'Intraoral Repair Kit' with sandblasting seemed to be an effective pretreatment that improves the porcelain-to-composite bond. It has been reported that microscopic cracks were produced when alumina particles were sandblasted to a ceramic surface, and that hydrofluoric acid penetrated along the groove and resin was able to penetrate deeply into the micromechanical undercuts.[15]

Adhesive materials containing 4-META (4-methacryloxyethyl trimellitate anhydride) as well as MDP have been shown to have good bonding properties to base metal alloys.[11,25,28] Improved bond strength to a metal surface might thus be expected if repair materials containing 4-META or MDP were used. As CoJet Sand was blasted, particles became embedded in the metal surface. A prehydrolyzed, 3-methacryloxypropyl trimethoxysilane coupling agent (γ-MPS) was then applied that forms covalent bonds between the silica particles and the adhesive.[29] Because alumina particles coated with silica were bound to the metal surface mechanically, the CoJet Repair System might display a better bond strength to alloy than the Intraoral Repair Kit. The resin bond strength of the CoJet Repair System was reported to have a range of 14.5-22.4 MPa to porcelain and 15.95-25.24 MPa to metal.[1,12,13,26] One study[1] reported that the CoJet Repair System displayed significantly higher bond strength to nickel-chromium alloy than to porcelain. In addition, Haselton and coworkers[12] reported no significant difference between the bond strength of a high noble alloy and feldspathic porcelain treated by the CoJet Repair System.

A porcelain repair procedure is not a permanent option. However, it may be often needed to rehabilitate appearance of failed restorations. Ozcan and Niedermeier[10] investigated 289 metal-ceramic restorations that were fractured during mean 34.6 months. These restorations were repaired with the CoJet Repair System and composite build-up. The overall cumulative survival rate was 89%, according to the Kaplan-Meier curve method. A repair procedure thus seems to be an alternative treatment, and moisture control is essential for a successful result. The specimens in this study were thermocycled for 1,000 cycles between 5°C and 55°C, as in previous studies.[1,13,14] After a review of the literature on thermal cycling procedures, Gale and Darvell[30] proposed that some 10,000 cycles might represent one service year, based on 20 to 50 cycles being equivalent to a single day. Thermal stress would weaken the porcelain-composite resin bond because of differences in the coefficients of thermal expansion and bond deterioration via hydrolysis.[31,32]

The present study involved a small number of specimens and thermal cycles. In addition, the procedures followed could not perfectly simulate the intraoral environment. Further studies subjecting a greater number of specimens to more thermal cycles and to a long period of storage in water should be explored in order to provide more reliable information about the repair systems studied.

CONCLUSION

Within the limitations of this study, sandblasting and application of the repair system I (Intraoral Repair Kit) can be suggested in the case of a fracture with exposed area of body porcelain. If the fracture extends to the metal surface, the repair system II (CoJet Repair System) is worthy of consideration.

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