Comparison of Repair Methods for Ceramic-Fused-to-Metal Crowns

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Purpose: The objective of this study was to evaluate the effect of four repair methods on the fracture load of repaired ceramic-fused-to-metal crowns.

Materials and Methods: Metal-ceramic crowns were fractured, and the failure load was measured. The fractured metal-ceramic crowns (n = 9) were assigned randomly to the following treatment groups: (1) hydrofluoric acid (9.5%) etching, (2) air-particle abrasion (50 μm Al_2O_3), (3) silica coating (30 μm SiO_x), and (4) the application of a layer of glass fiber-reinforced composite (FRC) (thickness: 0.12 mm) on the repair surface. The crowns were repaired with a highly filled resin composite and subjected to 3 repair cycles (n = 27). All specimens were stored in water at 37°C for 24 hours and then thermocycled (6000 cycles, 5°C to 55°C). The fracture load values for final failure of intact and repaired crowns were measured with a universal testing machine, and failure types were recorded.

Results: No significant differences ($p > 0.05$) were found between the final failure values for the groups treated with 9.5% hydrofluoric acid (376 N) and airborne particle abrasion with either Al_2O_3 (432 N) or SiO_x (582 N) followed by silanization, respectively. Significantly, higher ($p < 0.0001$) final failure values (885 N) were obtained with the use of the FRC layer when compared with the other repaired groups. There was no significant difference ($p > 0.05$) between the final fracture load of intact crowns (872 N) and those repaired with FRC (885 N) (One-way ANOVA with repeated measures, Bonferroni test). No significant difference in fracture loads was found between the 1st, 2nd, and 3rd repair cycles (558 N, 433 N, 485 N, respectively). Failure sites were predominantly at the alloy/veneering resin interface in Group 1; Groups 2 and 3 both showed more cohesive failures than Group 1. In the case of FRC, the failure pattern was exclusively cohesive between the two laminates of FRC layer.

Conclusions: The conditioning methods (Groups 1 to 3) of the repair surfaces did not show differences between each other; each resulted in mean fracture loads at lower levels than that of the intact crowns. Addition of an FRC layer increased the fracture load to the level of intact crowns. This suggests that the use of FRC in repairs of metal-ceramic crowns might be a viable option.

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INDEX WORDS: airborne particle abrasion, fiber-reinforced composite, hydrofluoric acid, repair, silica coating

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DESPITE THE INCREASED effort to improve the bond between ceramic materials and metal substrate, fractures of ceramic-fused-to-metal (CFM) restorations still occur. The reasons for fractures are frequently repeated stresses and strains during chewing or trauma.[1-6] Repairing CFM in vivo can increase the clinical longevity of the failed restorations, thereby offering the patient and the dentist a cost-effective alternative to replacement; however, the repair of fractured CFM crowns represents a potential clinical challenge, particularly when the metal substructure has been exposed, and when bonding of resin to metal alloy is required.[4,7]

The techniques for bonding of resin composites to alloys has improved over the past decade.[8] Recent developments in modern surface conditioning methods have resulted in improved resin-to-ceramic bond strengths.[9,10] All these new systems involve the conditioning of the surface with silane coupling agents.[11,12] The manufacturers of most of the new surface conditioning systems require airborne particle abrasion of the surface before bonding the resin composite to achieve high bond strength.

Fractured CFM restorations do not always involve metal exposure. Etching the fractured ceramic part of a crown with hydrofluoric (HF) acid followed by the application of a silane is a well known and recommended method to improve the attachment of composite resin to ceramic.[13-19] HF acid or acidulated phosphate fluoride may facilitate micromechanical retention, but these chemical agents are also known to have hazardous effects in vivo since they were found to be harmful and irritating compounds for soft tissues.[20,21]

The repaired restorations should also be resistant to fatigue. One alternative has been proposed with the use of fiber-reinforced composite (FRC), in which improved fatigue resistance of resin composites was noted.[22] Basically, by adding the FRC layer under the composite resin on CFM crowns, the FRC layer could offer reinforcement for the veneering resin composite.

Although, recent ceramic repair systems show sufficient adhesion of resin-based composites to the fractured ceramic and the exposed metal surfaces, failures are still being reported,[23-25] and there seems to be no consensus in the literature regarding the best method for repairing CFM restorations. Therefore, the objectives of this study were to evaluate the effect of four repair methods on the final fracture loads of CFM crowns repaired with resin composite and various surface conditioning methods and by adding glass FRC under the repair composite.

Materials and Methods

Experiments were made on the master dies of a prepared maxillary right central incisor on a phantom model (Frasaco, Tettnang, Germany) with 1.5 mm incisal reduction, 6 degree angle of convergence, and 1 mm shoulder. The metal dies were invested and cast out of a non-precious alloy (Co-Cr, Wirobond C,® Bego, Bremen, Germany). Feldspathic ceramic restorations (n = 9) with glazed surfaces (VITA Omega,® Shade A2, Vita Zahnfabrik GmbH, Bad Säckingen, Germany) were constructed on metal copings (Wirobond C®) by one experienced dental technician. A digital micrometer (Mitutoya Ltd, Hanshire, UK) was used to control 2 mm incisal thickness of the crowns at three locations. The shape and final crown contour was controlled on the phantom model. The crowns were then cemented to metal dies that had been previously cleaned in ethyl alcohol for 10 minutes with resin-based cement (Panavia® 21, Kuraray Co., Ltd., Osaka, Japan). The master die with the cemented crowns were then placed in polymethylmethacrylate (PMMA) (Palapress, Vario, Heraeus Kulzer, Wehrheim, Germany) molds with the long axis of the crown 45 degree relative to the horizontal plane. A loading test for the intact crown was performed using a universal testing machine (LRX Material Testing Machine, Lloyd Instruments, Brampton, Canada) at crosshead speed 1 mm/min, where the force was applied from the incisal direction with a 6 mm diameter steel ball (Fig 1).

The fractured CFM crowns were randomly assigned to the following treatment groups: (1) 9.5% hydrofluoric acid (Porcelain Etch, Ultradent® Products, Inc., South Jordan, UT) etching for 90 seconds, (2) air-particle abrasion with 50 μm Al_2O_3 alumina particles (Korox,® Bego), (3) silica coating (CoJet®-Sand, 30 μm SiO_x, 3M ESPE, Seefeld, Germany), and (4) the application of two layers of E-glass fiber-reinforced composite (Stick, StickTech Ltd., Helsinki, Finland) on the repair surface of the crown. This experimental design allowed for three repair cycles (n = 27) and one separate fiber treated repair cycle (n = 9) for the crowns (Fig 2). Between the repair cycles, the crowns were randomly assigned to the new repair cycle. The surface to be repaired was treated with air-particle abrasion using 50 μm alumina particles between the repair cycles.

Airborne particle abrasion using either Al_2O_3 or SiO_x (Groups 1 and 2) was achieved using an intraoral air abrasion device (Dento-Prep,™ RØNVIG A/S, Daugaard, Denmark) from a distance of approximately

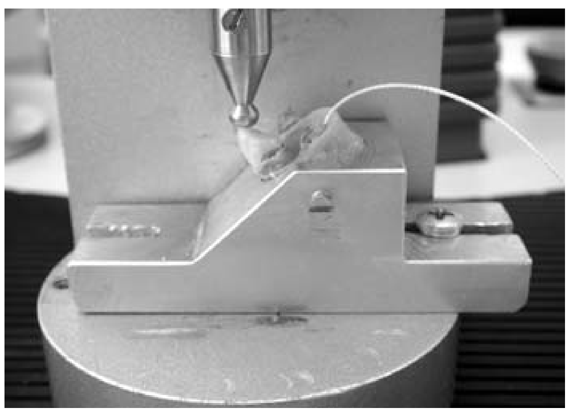

Figure 1. Test assembly where the load was applied to the crowns from the incisal direction.

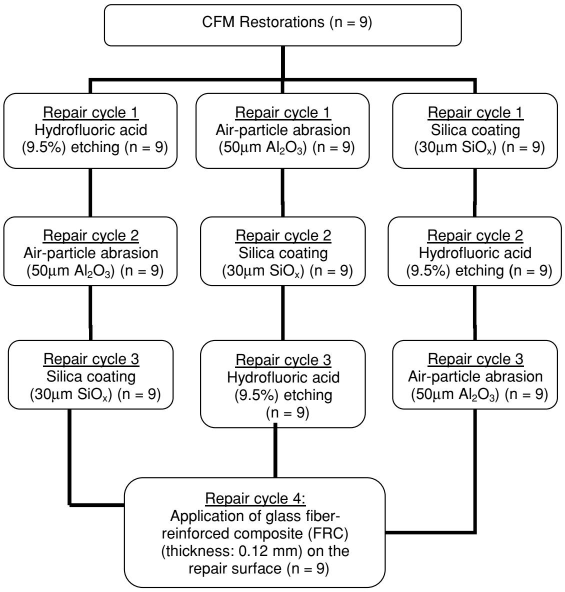

Figure 2. Experimental design of the study.

10 mm at a pressure of 250 kPa bar for about 10 seconds until the surface visually changed color. Each surface treatment was followed by silanization (ESPE®-Sil, 3M ESPE). The adhesive resin (Scotchbond Multipurpose Adhesive, 3M ESPE) was applied, and after the excess was blown away, the resin was light-polymerized (Optilux 501, Kerr, West Collins Orange, CA) for 10 seconds with light-intensity of 800 mW/cm^2. Opaquer was applied when metal was exposed (Visiogem, 3M ESPE) and light-polymerized for 20 seconds. The crowns were repaired with a highly filled (79 w-% filler) resin composite (Tetric Ceram, Shade A2, Vivadent Ivoclar, Schaan, Liechtenstein).

In the FRC group (Group 4), two pieces of polymer dimethacrylate-monomer gel impregnated photopolymerizing bidirectional E-glass fiber layers (thickness: 0.06 mm each) were cut and pressed against the repair surface of the crown. The layers did not extend to the marginal areas of the crown cervically or proximally and covered only the fractured surface. Adhesive resin (Scotchbond Multipurpose Adhesive) was applied between the fiber sheets. The two layers of FRC were light-polymerized for 40 seconds.

An incremental build-up technique with particulate filler resin composite (Tetric Ceram, Vivadent Ivoclar) was used to construct the veneer. The incisal thickness of each crown after the repair was verified to be 2 mm using a digital micrometer. All the restorations were finished wet. Fine diamond burs were used to remove the excess resin composite. Repair surfaces were further finished with coarse, medium, fine, and ultra-fine finishing disks (Sof-Lex, 3M ESPE).

The specimens were first stored in water at 37°C for 24 hours and then subjected to thermocycling (Thermocycler 2000, Heto-Holten A/S, Allerod, Denmark) for 6000 cycles between 5°C and 55°C in deionized grade 3 water. The dwelling time at each temperature was 30 seconds, and the transfer time from one bath to the other was 2 seconds. After thermocycling, a loading test was again performed for the final failure. Final failure (N) refers to the load that led to catastrophic failure of the restoration.

After each fracture test, the failure type and location were examined visually and digital photographs were taken (Nikon Coolpix 990, Tokyo, Japan).

Statistical analysis was performed using SAS System for Windows, release 8.02/2001. The means of each group for final failure and repair cycles were analyzed by one-way Analysis of Variance (ANOVA) with repeated measures and the Bonferroni test. p-Values less than 0.05 were considered to be statistically significant in all tests.

Results

Although there was a trend for higher fracture load values after thermocycling in the CFMs repaired using silica coating and silanization (582 ± 127 N), no significant differences ($p > 0.05$) were found between the final failure values for the groups treated with either 9.5% hydrofluoric acid (376 ± 155 N) or airborne particle abrasion with either Al_2O_3 (432 ± 132 N) followed by silanization (Fig 3*A*). Significantly higher final failure (885 ± 123 N) ($p < 0.0001$) values were obtained with the use of the FRC layer when compared with the other repaired groups. Furthermore, there was no significant difference ($p > 0.05$) between the final fracture load of intact crowns (872 ± 459 N) and those repaired with FRC (885 ± 123 N). No significant difference in mean fracture loads was found between the 1st, 2nd, and 3rd repair cycles (558 N, 433 N, 485 N, respectively) (Fig 3*B*).

Predominantly two types of failures were observed: adhesive failures (a) at the alloy/veneering resin interface with substantial detachment of the veneering resin or cohesive failures and (c) within the veneering resin. The adhesive failures observed in all groups involved opaquers attached to the resin composite (Fig 4*A*). While intact crowns exhibited mainly adhesive failures of ceramic with metal exposure (6a/3c), failure sites were mostly at the alloy/veneering resin interface in Group 1 (22a/5c); Groups 2 (18a/9c) and 3 (10a/17c) both showed more cohesive failures than Group 1. In

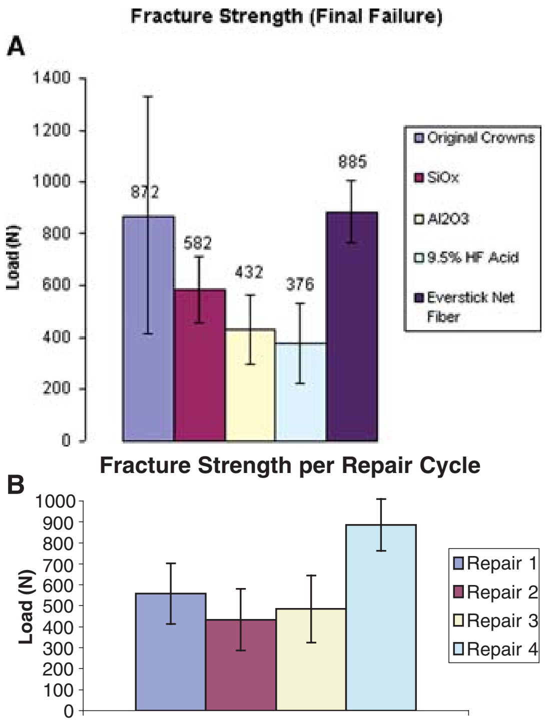

Figure 3. (*A*) Fracture load (N) at final failure of CFMs. (*B*) Fracture load (N) at each repair cycle.

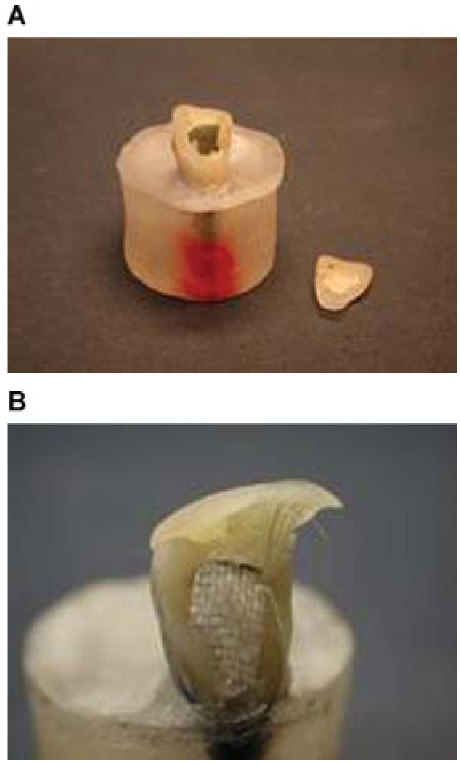

Figure 4. (*A*) A typical adhesive failure at the alloy/veneering resin interface with opaquer remaining on the resin composite. (*B*) A typical cohesive failure between the two layers of FRC.

the case of FRC layer application, the failure type was exclusively cohesive (9c), between the two layers of FRC laminates (Fig 4*B*).

Discussion

For the repaired restoration to withstand functional loads, a durable bond is desirable between the repair resin and the remaining restoration. Both experimental and clinical reports provide evidence of differences between the performance of repair techniques and are considered when providing interim treatment outcome. In an attempt to mimic the clinical failures, fractured CFM crowns having irregular fracture surfaces were used in this study.

The average masticatory forces are reported to be between 20 and 830 N in the literature.[26] The masticatory forces between the incisors vary between 155 and 222 N and are higher for molars—up to 830 N.[26]

In this study, although there was a trend for higher fracture load values in the CFMs repaired with silica coating followed by silanization, no significant difference was found in final failure compared with the groups repaired with either HF acid or airborne particle abrasion with alumina particles. In fact, the results after using these three methods followed by silanization exhibited mean fracture values (376 N to 582 N) that normally exceeded the reported masticatory force values. However, due to the disappointing clinical outcomes, especially with the use of HF acid,[27] it could be stated that the masticatory forces should not be taken as a reference to test the durability of a repair in clinical applications. It should also be noted that clinically, restorations also fail through cyclic load causing fatigue. It was observed that the intact crowns showed a high average fracture load value of 872 ± 459 N but also high standard deviations. One possible reason for this wide range could be attributed to the existing cracks or flaws within the ceramic since their fabrication relies on manual techniques.

One interesting finding of this study was the non-significant mean fracture load obtained from the group repaired with the layer of FRC and the intact crowns. The fiber weaves used in this study were impregnated with polymer-monomer gel resin. The exclusively cohesive failure type between the two FRC laminates in this group implies that the FRC provides a strong bond on the metal/ceramic surface and on the veneering resin composite. On the other hand, the delamination of FRC layers suggests that bonding of the laminates to each other was not optimal. This could be due to the existence of PMMA as the resin matrix of FRC. Polymethylmethacrylate enrichment on the fiber weave surface needs to be treated with a resin having a dissolving parameter of PMMA, or extensive resin treatment times are needed.

The higher results obtained with the use of FRC weaves could imply that the stress concentrations in the repaired crown cause initiation of a crack, and it propagates through the resin until it meets the FRC layer with continuous fibers and stops.[28]

Although the sample number was small, original crowns exhibited mainly adhesive failures with metal exposure; this finding is in accordance with recent clinical findings.[5] Since after each repair action and the following fracture test the surface area changes, performing repair studies on actual crowns is difficult. However, the controversial reports on the extrapolation of in vitro data obtained from disc specimens to the clinical situation often resulted in failures of CFM crowns indicating the need for clinical simulation in in vitro studies.[23] For this purpose, in this study the specimens were subjected to repair cycles where conditioning methods were applied in changing order. One could expect that after each repair cycle, the repair surface area changes, but this was the only manner to simulate multiple repair actions on non-uniform surfaces, which is the case in clinical situations. Interestingly, there was no significant difference in fracture loads between the repair cycles most probably because the strength of the repaired areas did not exceed the cohesive strength of the ceramic substrate. This could indicate that the weakest link is still the interface between the ceramic and/or metal and the repair composite. It should also be noted that the adhesive type of failures were observed more frequently in the HF-treated group when compared with the air-abraded and silanized groups. The cohesive type of failures could be considered more favorable for repair actions when compared to adhesive failures, where the clinician also needs to deal with masking the exposed metal surface with the opaquer. In future studies, the failure types should be emphasized as should the failure loads.

In spite of the limitations of this study, final fracture load values of repaired CFM crowns and the failure types provide additional information to the current knowledge. In clinical situations, the use of an FRC layer between the framework of the crown and the veneering composite might be a viable option for repairs of fractured veneer.

Conclusions

The following conclusions were made:

1. The conditioning methods using HF acid or airborne particle abrasion either with Al_2O_3 or SiO_x, followed by silanization did not differ from each other significantly, and the fracture load values obtained with these systems did not reach those of intact CFM crowns.
2. By using two layers of FRC between the framework of the crown and the repair composite resin, the original strength of the crown was reached.

References

1. Coornaert J, Adriaens P, de Boever J: Long-term clinical study of porcelain-fused-to-gold restorations. J Prosthet Dent 1984;51:338-342
2. Thurmond JW, Barkmeier WW, Wilwerding TM: Effect of porcelain surface treatments on bond strengths of composite resin bonded to porcelain. J Prosthet Dent 1994;72:355-359
3. Chadwick RG, Mason AG, Sharp W: Attempted evaluation of three porcelain repair systems—what are we really testing? J Oral Rehabil 1998;25:610-615
4. Tulunoglu IF, Beydemir B: Resin shear bond strength to porcelain and a base metal alloy using two polymerization schemes. J Prosthet Dent 2000;83:181-186
5. Özcan M, Niedermeier W: Clinical study on the reasons for and location of failures of metal-ceramic restorations and survival of repairs. Int J Prosthodont 2002;15:299-302
6. Özcan M: Fracture reasons in ceramic-fused-to-metal restorations. J Oral Rehabil 2003;30:265-269
7. Knight JS, Sneed WD, Wilson MC: Strengths of composite bonded to base metal alloy using dentin bonding systems. J Prosthet Dent 2000;84:149-153
8. Özcan M, Pfeiffer P, Nergiz İ: A brief history and current status of metal-and ceramic surface-conditioning concepts for resin bonding in dentistry. Quintessence Int 1998;29:713-724

9. Kern M, Thompson VP: Sandblasting and silica coating of a glass-infiltrated alumina ceramic: volume loss, morphology, and changes in the surface composition. J Prosthet Dent 1994;71:453-461
10. Özcan M, Alkumru HN, Gemalmaz D: The effect of surface treatment on the shear bond strength of luting cement to a glass-infiltrated alumina ceramic. Int J Prosthodont 2001;14:335-339
11. Özcan M, Akkaya A: New approach to bonding all-ceramic adhesive fixed partial dentures: a clinical report. J Prosthet Dent 2002;88:252-254
12. Özcan M, Vallittu PK: Effect of surface conditioning methods on the bond strength of luting cement to ceramics. Dent Mater 2003;19:725-731
13. Stangel I, Nathanson D, Hsu CS: Shear strength of the composite bond to etched porcelain. J Dent Res 1987;66:1460-1465
14. Diaz-Arnold AM, Schneider RL, Aquilino SA: Bond strengths of intraoral porcelain repair materials. J Prosthet Dent 1989;61:305-309
15. Wolf DM, Powers JM, O'Keefe KL: Bond strength of composite to porcelain treated with new porcelain repair agents. Dent Mater 1992;8:158-161
16. Thurmond JW, Barkmeier WW, Wilwerding TM: Effect of porcelain surface treatments on bond strengths of composite resin bonded to porcelain. J Prosthet Dent 1994;72:355-359
17. Tylka DF, Stewart GP: Comparison of acidulated phosphate fluoride gel and hydrofluoric acid etchants for porcelain-composite repair. J Prosthet Dent 1994;72:121-127
18. Aida M, Hayakawa T, Mizukawa K: Adhesion of composite to porcelain with various surface conditions. J Prosthet Dent 1995;73:464-470
19. Nicholls JI: Tensile bond of resin cements to porcelain veneers. J Prosthet Dent 1998;60:443-447
20. Bertolotti RL, Lacy AM, Watanabe LG: Adhesive monomers for porcelain repair. Int J Prosthodont 1989;2:483-489
21. Llobell A, Nicholls JI, Kois JC, et al: Fatigue life of porcelain repair systems. Int J Prosthodont 1992;5:205-213
22. Vallittu PK: Use of woven glass fibres to reinforce a composite veneer. A fracture resistance and acoustic emission study. J Oral Rehabil 2002;29:423-429
23. Özcan M: Evaluation of alternative intra-oral repair techniques for fractured ceramic-fused-to-metal restorations. J Oral Rehabil 2003;30:194-203
24. Edelhoff D, Marx R, Spiekermann H, et al: Clinical use of an intraoral silicoating technique. J Esthet Restor Dent 2001;13:350-356
25. Özcan M: The use of chairside silica coating for different dental applications: a clinical report. J Prosthet Dent 2002;87:469-472
26. Vallittu PK, Könönen M: Biomedical aspects and material properties. In: Karlsson S, Nilner K, Dahl BL, eds. A Textbook of Fixed Prosthodontics. A Scandinavian Approach. Gothia, Stockholm, Sweden, 2000, pp 116-130
27. Creugers NH, Snoek PA, Käyser AF: An experimental porcelain repair system evaluated under controlled clinical conditions. J Prosthet Dent 1992;68:724-727
28. Vallittu PK: Acrylic resin-fiber composite-Part II: The effect of polymerization shrinkage of polymethyl methacrylate applied to fiber roving on transverse strength. J Prosthet Dent 1994;71:613-617