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Original Article

Repair strength of dimethacrylate-based composites resins: Effect of sandblasting, adhesive bonding, and thermocycling

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ABSTRACT

Background: The goal of this study is to determine the effect of different sandblasting particles and dental adhesive systems on the repair strength of dimethacrylate-based composite resins.
Materials and Methods: In this *in-vitro* study, 96 specimens of X-trafil composite blocks were prepared and divided into eight groups ($n = 12$). Four groups were sandblasted with Aluminum Oxide (AL) and four other groups with Bio-Active Glass particles (BAG). A two-component silane was applied on the surface of all the samples after phosphoric acid etching and rinsing. Two groups of the sandblasted specimens were treated with Clearfil SE Bond (CSB) and the other two groups were treated with Single Bond Universal (SBU) and new composite was bonded to the prepared surfaces. Half of the specimens in each group were thermocycled. Shear force was applied to the bonded composite using a universal testing machine with a crosshead speed of 0.5 mm/min and mean shear bond strength (MSBS) was calculated (MPa). The data was analyzed using Kruskal–Wallis and Man–Whitney *U*-tests with the significance level of 0.05.
Results: Significant differences were observed between different groups ($P < 0.001$). The highest and the lowest MSBS of the thermocycled samples were reported 18.88 MPa with application of AL and SBU and 11.46 MPa with the application of AL and CSB, respectively. No significant difference was observed with application of BAG particles after thermocycling.
Conclusion: Effect of AL on repair shear bond strength of composite resins is affected by bonding type. Bonding type did not affect repair shear bond strength of BAG. Thermocycling reduced bond strength in all groups.

Key Words: Air abrasion, composite resin, dental bonding, dental restoration repair

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INTRODUCTION

Nowadays, composite resins are used to restore teeth damaged from decay or fractures. In addition, demands for esthetic treatments on anterior teeth are increasing and composite resins are among the materials used for these treatment plans. As a restorative material, composite resins have certain advantages including esthetics, bonding to tooth structure, high conservative restorations, and possibility of repair in case of fracture. Microleakage, discolorations, technique sensitivity, low mechanical properties, and risk of restoration fracture are among

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the limitations of composite resins. In a clinical situation, it is the dentist's decision to repair or replace defective composite restoration. It has been reported that 10-year mean annual failure of anterior and posterior composite restorations are 3.1% and 4.1%, respectively. This failure rate decreases to 2.6% and 2.9% for anterior and posterior composite restorations after restoration repair.[1]

The decision for repair and/or replacement of composite resin restorations is one of the challenges in dental practice. Complete debonding, fracture, chipping, and color change of the restoration are among the most common reasons for composite resin replacement and/or repair. Complete replacement of composites is considered the most common method in these situations and it involves the risk of damage to the tooth structure and pulp. Replacement of the old composite is time-consuming and expensive. On the other hand, repair of composite resin restorations seems to be a more conservative method, which provides greater serviceability for patients over a longer period of time.[2-4] A successful and effective repair of composite resin restoration requires a strong bond between the old and new composites. Arguably, the best method to create this bond is controversial between different studies.[5,6] It appears that the introduction of universal bonding systems with special chemical components, such as 10-Methacryloyloxydecyl dihydrogen phosphate (MDP) and silane in their composition, can be effective in repairing old composite restorations.[7]

In general, many studies have supported the positive effect of surface preparation on the bond strength of repaired old composite restorations.[8,9] Surface preparation for composite restorations is performed to remove the superficial layer altered by saliva, thus exposing a clean surface with a higher surface energy. In addition, surface preparation increases the surface area through the creation of irregularities.[10] There are mechanical and chemical methods to prepare the composite resin restoration surface. Chemical methods include application of acid etching,[10] silane[11,12] or adhesives[9] and mechanical methods include bur roughening and sandblasting.[13] One of the most effective mechanical methods for the preparation of composite surface is sandblasting with alumina particles together with the application of etching acids.[7] Many studies have shown that using methods such as application of adhesives, silane and sandblasting improve the bond strength of the new to the old composite.[8,14] However, Bacchi reported that these chemical or mechanical methods have no effect on the bond strength of the repaired composite.[9]

Different studies have used several procedures for the aging process to simulate oral environmental conditions and the effect of time on the bond strength of repaired composites. These procedures include boiling,[5,8] immersion in acid,[7] abrasion with the aid of silicon carbide burrs,[15] immersion in distilled water for different periods and thermocycling.[16,17] Among them, thermocycling is more effective and is a common aging procedure in bond strength evaluation tests to resemble oral condition and to assess the effect of thermal stresses on bond durability.[7,8]

Alumina particles are commonly used to sandblast composite resin restorations.[11,14] Recently, Bio-Active Glass particles (BAG) are used as a sandblasting agent.[18-20] Moreover, universal adhesives with the capability of bonding to different dental substrates have been introduced. Therefore, the aim of this study is to determine the effect of sandblasting with BAG and aluminum oxide (AL) particles and two types of bonding systems on repair shear bond strength of dimethacrylate composites. The null hypothesis of this study states that (1) BAG particles as sandblasting powder exhibit higher repair shear bond strength than that of AL and (2) universal dental bondings are as effective as two-step self-etching systems.

MATERIALS AND METHODS

The research protocol of this study was approved by the Ethics Research Committee of Isfahan University of Medical Sciences, Iran (#396178). In this *in vitro* study, 96 specimens of composite resin blocks (X-trafil, Voco, Germany) with dimensions of 5 mm × 5 × 2 mm were prepared ($\alpha = 0.05$). The composite was packed into plastic molds and covered with transparent strips. A glass slab with a thickness of 1.5 mm was placed on the composite surface under finger pressure. Next, the composite was light-cured with a Valo light-curing unit (Ultradent, Germany) at an intensity of 800 mW/cm^2 for 20 s. The samples were finished using diamond burs (Meisinger, Germany). All the specimens were kept in distilled water at 37°C for 24 h. Then, the specimens were randomly divided into eight groups ($n = 12$). Four groups were sandblasted with 50-µm AL (Pardis Pazhoohesh Fanavaran Yazd [Apatech™], Iran), while 50-µm BAG particle (Pardis Pazhoohesh Fanavaran

Yazd [Apatech™], Iran) was used for sandblasting the other four groups. Sandblasting was carried out using a microblaster device (Dento-Prep Microblaster, Denmark) at a distance of 10 mm perpendicular to the surface of the specimen and a pressure of 60 Psi for 3 sec. Each specimen was rinsed under air/water spray for 20 s and dried for 5 s. In the next stage, the sandblasted surface of each specimen was etched using 37% phosphoric acid (UltraEtch, Ultradent) for 20 sec, rinsed under air/water spray for 20 s and dried again for 5 s. Then, the two components of Bis-Silane (Bisco, USA) were mixed according to the manufacturer's instructions and applied to the surface of each specimen for 20 s and air dried for 5 s. The specimens were rinsed with 60°-70°C water for 5 s and finally air-dried for 20 s.

In the next step, dental adhesives [Table 1] were applied on the prepared surfaces of each group specimen [Table 2]. Primer component of the Clearfil SE Bond (Kuraray, Osaka, Japan) (CSB) was applied with a microbrush to the prepared surface for 15 s and completely air-dried. Then, the adhesive component was applied with a microbrush and air-thinned for 5 s and light-cured. Single Bond Universal (SBU) (3M ESPE, St. Paul, MN, USA) was applied to the surface for 15 sec, air-thinned for 5 s, and light-cured. To this end, ortho-ring (Ortho Organizers Inc., Carlsbad, USA) was placed on the surface of each specimen and the X-trafil composite resin was packed inside the ring and light cured with the aid of transparent strips and pressure on glass slab. The specimens were kept in 37°C distilled water for 1 month.

Finally, half of the samples were subjected to a thermocycling test (Delta Tpo2, Nemo, Iran) between 5°C and 55°C and a dwell time of 10 s in 37°C for 10,000 cycles. The shear bond strength of repaired composite was measured using a Universal Instron testing machine (K-21046, Walter + bai, Switzerland) for each specimen at a crosshead speed of 0.5 mm/min. Sample preparation in different groups is presented in Figure 1.

The mean shear bond strength (MSBS) of each group was calculated in Master of Public Administration (MPa) and the data was analyzed using the SPSS software (IBM SPSS Statistics, v24, IBM Corp., Armonk, NY, USA). Kruskal–Wallis and Man–Whitney *U*-tests were used to compare the MSBS of repaired composite in different groups. The significance level was considered 0.05 in this study.

RESULTS

According to the Kruskal–Wallis test, significant differences were observed between different groups ($P < 0.001$). The MSBS of each group and comparison

Table 1: Materials used in this study

Material	Composition	Manufacturer
Clearfil SE bond (Two-Step Self-Etch Bonding System)	Primer: HEMA, hydrophilic di-methacrylates, 10-MDP, diethanol-toluidine, camphorquinone, and water	Kuraray, Osaka, Japan
	Adhesive: Silanized colloidal silica, HEMA, hydrophilic methacrylates, Bis-GMA, 10-MDP, diethanol-toluidine, and camphorquinone (27)	Kuraray, Osaka, Japan
Single Bond Universal (Universal Bonding System)	MDP phosphate monomers, dimethacrylate resins, HEMA, vitrebond copolymer, PAAC, filler, ethanol, water, primer, and silane (27)	3M ESPE, St. Paul, MN, USA
X-trafi (Posterior Bulk-fill Composite Resin)	Bis-GMA, UDMA, TEGDMA, inorganic fillers, fumed silica, CQ photoinitiator, photoaccelerator (34)	Voco, GmbH, Cuxhawen, Germany

PAAC: Polyalkenoic acid, MDP: Methcryloylxydecyl Dihydrogen Phosphate, HEMA: Hydroxyethyl Methacrylate

Table 2: Sample preparation and mean shear bond strength (MPa) of different groups

Group	Treatment	Mean SBS±SD	Minimum	Maximum	Lower bound (CI 95%)	Upper bound (CI 95%)
1 (AL/CSB/T)[a]	Al2O3 + CSB + Th	11.46±5.55	4.33	23.68	7.92	14.98
2 (BG/CSB/T)[a, b, f, g]	BAG + CSB + Th	14.89±5.95	7.56	25.26	11.10	18.67
3 (AL/SBU/T)[b, e, g]	Al2O3 + SBU + Th	18.88±5.44	5.44	29.88	15.42	22.33
4 (BG/SBU/T)[b, f]	BAG + SBU + Th	18.15±4.37	4.37	22.72	15.37	20.94
5 (AL/CSB)[b, d]	Al2O3 + CSB	21.08±11.67	11.67	36.99	13.67	28.50
6 (BG/CSB)[c, d]	BAG + CSB	25.11±8.37	8.37	34.19	19.79	30.43
7 (AL/SBU)[d]	Al2O3 + SBU	26.68±6.77	6.77	37.44	22.38	30.98
8 (BG/SBU)[e, d]	BAG + SBU	23.68±4.51	4.51	29.06	20.81	26.55

Groups with same superscript have no significant difference. SBS: Shear bond strength, SD: Standard deviation, CI: Confidence interval for mean, Al2O3: Aluminum oxide sandblasting particle, BAG: Bioactive glass sandblasting particle, CSB: Clearfil SE bond, SBU: Single bond universal, Th: Thermocycling between different groups based on Man–Whitney test are presented in Table 2 and Figure 2. The highest and the lowest MSBS of the nonthermocycled groups were reported in Group 7 (Al/SBU) (26.68 MPa) and group 5 (AL/CSB) (21.08 MPa), respectively. Among the thermocycled groups, the highest and lowest MSBS s were 18.88 MPa and 11.46 MPa in Groups 3 (AL/SBU/T) and 1 (AL/CSB/T), respectively.

DISCUSSION

One of the limitations of composite resin materials as a restoration is chipping and fracturing of the restoration over time. In these situations, repair of the restoration instead of replacement is a treatment that should be considered as a minimally invasive method. The annual failure rate of composite restorations is reported 1.6% and this failure rate increases to 5.7% for repaired composite restorations at 4 years.[21] Adhesion between two layers of fresh composite is accomplished through oxygen-inhibited layer. When repairing an old composite restoration, this layer does not exist and it is necessary to treat the surface of the old composite to bond new composite to it. The weakest part of the repaired composite restoration is the interface between the old and the new composites.[22] In order to bond new composite restoration to the old restoration, mechanical and chemical surface treatments including sandblasting, bur roughening, acid etching, application of silane, and dental adhesives are recommended. Although different surface treatment methods are available, there is no definitive protocol in the literature which results in the best bond between old and new composite and there are many debates about the best method for repairing composite resins.[23]

In this *in-vitro* study, the repair shear bond strength of composite restorations with different methods of surface preparation was investigated [Table 2 and Figure 2]. The conditions for parametric tests, including data normality and homogeneity of variance are not met. Instead, we used nonparametric alternatives, namely the Kruskal–Wallis and Man–Whitney *U*-tests to compare data set. The null hypothesis of the study was that sandblasting with BAG particles results in higher repair bond strength of composite resin restoration. According to the results presented in Table 2, the null hypothesis was not confirmed; no significant differences were observed between the efficacy of two types of sandblasting particles used in this investigation.

In this study, the mean repair shear bond strength of Groups 2(BG/CSB/T), 3(AL/SBU/T) and 4(BG/SBU/T) are in the range of about 15–25 MPa, which is clinically acceptable. Comparisons between Groups 1 (AL/CSB/T) and 2 (BG/CSB/T) ($P = 0.33$), Groups 3(Al/SBU/T) and 4 (BG/SBU/T) ($P = 0.82$), Groups 5 (AL/CSB) and 6 (BG/CSB) ($P = 0.083$) and groups 7 (AL/SBU) and 8 (BG/SBU)($P = 0.616$) shows that the type of utilized sandblasting particle has no effect on the bonding efficacy of CSB and SBU before and after thermocycling. AL powder with different particle size is one of the most common sandblasting particles used in dental treatments for different purposes, such as cleaning the investments, roughening of the restoration surface and dental substrate preparation.[24] In recent years, BAG has been proposed as a sandblasting agent[19,20] with the capability of bonding to hydroxyapatite and has mainly been used to repair bone defects around the tooth root.[25] The cutting efficacy of the air abrasion technique depends on various factors, including the shape and size of the powder particles, distance between the nozzle tip and the tooth or restoration surface, power flow, duration of sandblasting and air pressure.[20] Sandblasting of restoration surface increases surface energy, which promotes bonding

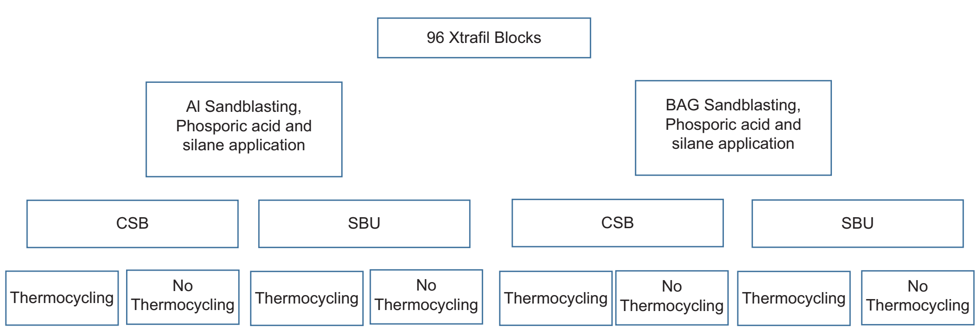

Figure 1: Sample preparation in different groups. AL: Aluminium Oxide particle, BAG: Bio Active Glass particle, CSB: Clearfil SE Bond, SBU: Single Bond Universal.

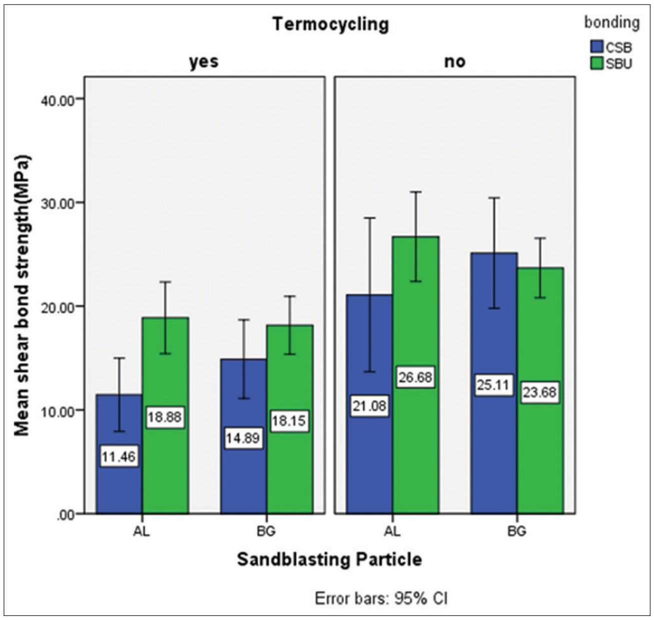

Figure 2: Mean shear bond strength of different groups.

quality. It seems that the hardness and size of both types of sandblasting particles used in this study were sufficient to create surface irregularities at the composite surface. The sizes of both types of particles used in this study were identical (50 microns). The Knoop hardness (KHN) of alumina powder is 2100 compared to a value of 420 for BAG.[20] The KHN of X-trafil® composite used in this study is 84.38,[26] which is of course lower than the hardness of Alumina and BAG powder.

The results of this study show that the second null hypothesis of the present study depends on the sample preparation method. The lowest MSBS was observed in Group 1 (AL/CSB/T), which is significantly different from the other groups, except for Group 2 (BG/CSB/T). This finding shows that if Al_2O_3 particles are used for sandblasting, the bonding type has a significant effect on the shear bond strength ($P = 0.28$) and application of SBU creates a higher shear bond strength. There are some differences between the composition of the two adhesives, CSB and SBU, used in this study [Table 1].[27] First, SBU contains polyalkenoic acid (PAAC) in its composition.[28] The presence of PAAC should be considered as a factor that increases the resistance of bonding to moisture. The second difference is the concentration of 10-MDP in SBU, which is higher than the value in CSB.[29] 10-MDP is a functional molecule with the ability of bond to different substrates, which creates a stable nano-layer at the adhesive interface.[23] Higher concentration of 10-MDP in the composition of SBU creates more stable bonds with the surface of old composite. In addition, SBU contains silane in the composition, which is not present in the composition of CSB. Silane acts as a functional molecule that promotes bond to different substrates.[27] Gamma-methacryloxypropyltrimethoxysilane, one of the most widely used silanes in dentistry, is present in the composition of SBU adhesives.[30] Silane establishes a strong bond to silica-based materials, which is one of the main filler particles available in the chemical composition of composite resins.[8] Based on these features, the significant difference between Group 1 (AL/CSB/T) and three (AL/SBU/T) can be explained ($P = 0.028$). In addition, the shear bond strength of Group 4 was higher than Group 2 but the difference was not significant ($P = 0.323$).

The shear bond strength of all groups was significantly reduced after thermocycling [Table 2] and the lowest shear bond strength was observed in Group 1 (AL/CSB/T). Findings of the present study shows that thermal stresses caused degradation of bond between the old and new composites that reduced the repair bond strength. Thermocycling test is a common method to evaluate the effect of thermal stresses on the adhesive interfaces in bond strength tests.[7,8]

It has been shown in many studies that mechanical treatment of composite restoration surface is a critical step to create bond with new composite. Among the different mechanical methods, sandblasting with Al_2O_3 is one of the best methods.[31] Many studies concluded that air abrasion with Al_2O_3 creates higher bond strength of repair composite resin.[23] Phosphoric acid application results in more surface area, more clean surface, and exposure of underlying surface. In a study, conducted by Loomans *et al*.,[6] about the effect of different etching methods on surface roughness of composite resins, it was concluded that the surface roughness of composite resins does not change after phosphoric acid application. Another study showed that acid etching with phosphoric acid, after surface roughening of the composite resin surface with silicon carbide paper, creates micro-and macro-retentive irregularities.[23] In our study, we used phosphoric acid after air abrasion to dissolve air abrasion debris and to clean composite surface after air abrasion.

The effect of silane included in the composition of some universal adhesives on bond strength of composite resin repair is controversial. There are some studies that show a separate application of silane has no effect on bond strength of universal adhesive to repair composite resin restorations.[31] In a study, by Fornazari *et al*.,[32] on the microshear bond strength of composite resin repair using universal adhesive, it was concluded that air abrasion increases repair bond strength and application of universal adhesive containing silane creates bonds as effective as separate application of silane with adhesive. Michelotti *et al*.[31] concluded that separate application of silane prior to universal adhesive application does not increase the repair bond strength. In groups that conventional adhesive was used, the effect of separate silane application was significant. These findings are similar to our results in the groups that Al_2O_3 was used as sandblasting powder. Application of SBU, which contains silane in the composition, creates higher repair bond strength than CSB in the groups that Al_2O_3 was used as the sandblasting agent (P = 0.028). However, in groups that BAG was used as the sandblasting powder, there was no significant difference between the effectiveness of the two applied adhesives (P = 0.323), as discussed before. Comparison between Groups 2 (BG/CSB/T) and 4(BG/SBU/T) shows that the bonding type has no effect on the shear bond strength of the new to the old composite, if BAG is used as the sandblasting particle (P = 0.323). This effect could be related to the effect of glass particles in the sandblasting powder, which is similar to filler particles available in the chemical composition of composite composition and is capable of creating bonds with 10-MDP molecules available in both types of adhesives used in this study. Oglakcia and Arhun[22] report that the adhesive type did not affect repair shear bond strength, which differs from the results of the present study. However, Oglakcia reported that the type of composite resin used to repair affected the shear bond strength.

It appears that the bond strength of repaired composite restorations depends on many factors, including chemical composition of the composite, type of bonding, surface preparation method, and storage time. One of the limitations of the present study is that only two types of dental bondings along with Al_2O_3 or BAG sandblasting were used. It is suggested for future studies to evaluate the repair bond strength of composite resins with other bonding systems and different preparation methods.

CONCLUSION

Within the limitations of this *in-vitro* study:

1. With similar bonding systems, the type of sandblasting particles does not affect repair shear bond strength of composite restorations, and both types of particles, AL or BAG, may be used for this purpose.
2. If AL is used as sandblasting particle, application of SBU results in higher shear bond strength of composite repair than CSB
3. If BAG is used as sandblasting particle, there is no difference between repair shear bond strength of SBU and CSB
4. Thermocycling reduced repair bond strength of composite resin restoration in all groups.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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