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BASIC RESEARCH:

Bond Strength of Bulk-Fill Resin Repairs: Impact of Surface and Adhesive Protocols

Resistencia de unión en reparaciones con resina bulk-fill: impacto de los protocolos de superficie y adhesivos

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ABSTRACT: Although repair is a conservative approach that preserves healthy tooth structure, there is still no consensus on the most effective surface treatment and adhesive protocol for repairing aged bulk-fill composite resin restorations. The objective of the study was to evaluate the effect of diamond bur roughening and aluminum oxide (Al_2O_3) sandblasting as surface treatments combined with different adhesive protocols on the repair bond strength (BS) of aged bulk-fill composite resin.150 Filtek™ One resin discs were thermocycled (5,000 cycles of 5°/55°C) and divided into three surface treatment groups (n=50): no treatment (NT), roughening with diamond bur (B), and sandblasting with Al_2O_3 (Al). Each group was further subdivided according to five adhesive protocols (n=10): no adhesive (NA), Adper Single Bond 2 (SB), Single Bond Universal (SBU), Silane + Adper Single Bond 2 (S+SB), and Silane (S). Three Bulk Fill resin cylinders were fabricated for each specimen to simulate repair, followed by micro-shear bond strength testing and fracture pattern analysis after 24-hour storage in deionized water. Two-way ANOVA and Tukey's test (α=0.05) were applied. When B or Al was applied, only NA showed inferior results. No statistical differences were found between B/SB, B/SBU, B/S+SB, and B/S, as well as between Al/SB, Al/SBU, Al/S+SB, and Al/S. Al/SBU showed higher bond strength than B/SBU. The most frequent fracture patterns for B and Al were cohesive and mixed, while for NT, it was adhesive. Surface treatment with B or Al, combined with an adhesive protocol, improved bond strength. Surface treatment is crucial for bulk-fill composite resin repair, enhancing bond strength with adhesive systems, with or without silane. A universal adhesive containing silane is as effective as adhesive-silane combinations, offering superior bond strength on Al_2O_3 blast-treated surfaces.

KEYWORDS: Bulk fill; Resin; Composite; Surface treatment; Silane; Repair.

RESUMEN: Aunque la reparación es un enfoque conservador que preserva la estructura dental sana, no existe consenso sobre el tratamiento de superficie ni el protocolo adhesivo más eficaz para restauraciones de resina compuesta bulk-fill. Este estudio evaluó el efecto del asperizado con fresa diamantada y del arenado con óxido de aluminio (Al_2O_3, combinados con distintos protocolos adhesivos, sobre la resistencia de unión de reparación (BS) de resina compuesta bulk-fill envejecida. Se fabricaron 150 discos de resina Filtek™ One, sometidos a termociclado (5.000 ciclos de 5°/55 °C) y divididos en tres grupos de superficie (n=50): sin tratamiento (NT), asperizado con fresa diamantada (B) y arenado con Al_2O_3 (Al). Cada grupo se subdividió según cinco protocolos adhesivos (n=10): sin adhesivo (NA), Adper Single Bond 2 (SB), Single Bond Universal (SBU), Silano+Adper Single Bond 2 (S+SB) y Silano (S). Se fabricaron tres cilindros de resina Bulk Fill por espécimen para simular la reparación. Luego se evaluó BS mediante microcizallamiento y se analizó el patrón de fractura tras 24 horas de almacenamiento en agua. Los datos se analizaron mediante ANOVA de dos vías y prueba de Tukey (α=0,05). Con B o Al, solo NA mostró resultados inferiores. No se observaron diferencias significativas entre B/SB, B/SBU, B/S+SB y B/S, ni entre Al/SB, Al/SBU, Al/S+SB y Al/S. Al/SBU presentó mayor BS que B/SBU. Los patrones de fractura más frecuentes para B y Al fueron cohesivos y mixtos, mientras que para NT predominó el adhesivo. En conclusión, el tratamiento de superficie con B o Al, combinado con un protocolo adhesivo, mejora la BS. El tratamiento de superficie es clave para la reparación de resina compuesta bulk-fill, potenciando la eficacia de los sistemas adhesivos con o sin silano. Un adhesivo universal es tan eficaz como la combinación adhesivo-silano, ofreciendo mayor BS en superficies tratadas con arenado de Al_2O_3.

PALABRAS CLAVE: Bulk-fill; Resina; Compuesto; Tratamiento de superficies; Silano; Reparación.

INTRODUCTION

Composite resin restorations are widely used in clinical practice due to their esthetic properties and adhesive capabilities, which allow for greater preservation of healthy dental structure (1-3). The use of bulk-fill composite resins has steadily increased because of the simplified insertion technique they allow in cavities to be restored (4). However, changes such as temperature and pH fluctuations, as well as masticatory forces in the oral cavity, can lead to degradation of this material over time, necessitating new interventions (5,6). This degradation may result in recurrent caries, marginal defects, fractures of the restorative material or adjacent dental structures, or even discoloration, ultimately creating the need for restoration replacement (7). In such cases, two interventions are possible: replacement of the restoration or repair. However, replacing a restoration may result in the unnecessary removal of healthy dental structure, which contradicts the philosophy of minimally invasive dentistry (8-10).

The success of a repair depends on the presence of unreacted monomers in the composite resin's organic matrix, which are available to chemically bond with the new composite increment (11,12). However, during aging in the oral environment, these unreacted monomers are leached out, and the resin matrix absorbs water, making it difficult to establish chemical bonding with a new composite due to the reduction in available C=C bonds (11,13,14). These bonds enable bonding to the monomers of the new composite, promoting adhesion (15). To overcome the lack of chemical affinity between the aged resin and the new repair material, various techniques have been proposed to enhance the bond strength of composite resins. These include surface treatments and the use of adhesive agents, such as phosphoric or hydrofluoric acid conditioning, diamond bur roughening, aluminum oxide (Al_2O_3) sandblasting, tribochemical silica coating, silane treatment, and the application of resin adhesives (13,16-21).

Surface roughening increases the adhesive potential of the substrate by creating microretentive areas that facilitate micromechanical interlocking between components (22-24). Silane improves the interaction between the adhesive agent and the irregularities created by surface treatment (25-27). This occurs because silane contains two functional groups: silanol, which bonds to the silica in the composite's filler particles through covalent carbon-carbon (C=C) bonds, and an organofunctional group, which is copolymerized with the methacrylate monomers in the adhesive, enabling chemical bonding during the adhesion process. The effectiveness of silane chemical coupling depends on the availability of silica (glass particles) in the composite being repaired (26,28).

Adhesive systems, due to their low viscosity and high fluidity, can more easily flow over the substrate, acting as an intermediate agent between the composite resin and the surface to be repaired (29,30). Therefore, they are consistently essential in composite resin repair protocols. Furthermore, universal adhesive systems containing silane in their formulations have been proposed as a potential strategy to enhance adhesion; however, current findings in the literature remain inconclusive and indicate the need for further investigation (31).

Although the efficacy of different repair techniques for resin materials has been discussed in the literature, there is still no standardized protocol or consensus regarding the ideal materials for composite resin repairs (31). Therefore, the best approach for repairing bulk-fill composite resin restorations remains unclear, and it is still unknown whether the prior application of silane enhances adhesion to this type of material.

This *in vitro* study aimed to evaluate the effects of diamond bur roughening and aluminum oxide sandblasting as surface treatments, as well as different adhesive protocols-with or without the use of silane-on the repair of aged bulk-fill composite resin. Thus, two null hypotheses were proposed: (1) surface treatment does not influence bond strength in repairs of bulk-fill composite resin; and (2) the adhesive system protocol does not affect bond strength values in repairs of bulk-fill composite resin.

MATERIAL AND METHODS

EXPERIMENTAL DESIGN

A randomized design was used with two factors: (1) Surface treatment No treatment (NT, control), diamond bur roughening (B), and Al_2O_3sandblasting (Al); (2) Adhesive protocol — No adhesive (NA, control), Adper Single Bond 2 (SB), Single Bond Universal (SBU), Silane + SB (S+SB), and Silane only (S) (Table 1).

Table 1. Experimental groups (n=10).

Surface treatment	Adhesive protocol	Group
No treatment	No adhesive	NT/NA
	Adper Single Bond 2	NT/SB
	Single Bond Universal	NT/SBU
	Silane + Adper Single Bond 2	NT/S+SB
	Silane	NT/S
Diamond bur	No adhesive	B/NA
	Adper Single Bond 2	B/SB
	Single Bond Universal	B/SBU
	Silane + Adper Single Bond 2	B/S+SB
	Silane	B/S
Sandblasting with Al_2O_3	No adhesive	Al/NA
	Adper Single Bond 2	Al/SB
	Single Bond Universal	Al/SBU
	Silane + Adper Single Bond 2	Al/S+SB
	Silane	Al/S

PREPARATION OF SPECIMENS

A total of 150 specimens were fabricated using Filtek™ One Bulk Fill composite resin (3M ESPE), shade A2 (Figure 1), in a 10 mm × 1.2 mm aluminum matrix (Figure 2.A). The composite was placed on a glass slide with a polyester strip, inserted with a Suprafil #2 spatula, covered with a new strip and glass slide, compressed, and light-cured for 20 s using an LED curing unit (Valo, Ultradent Product Inc.). Specimens were stored in deionized water at 37 °C for 24 h and then embedded in colorless self-curing acrylic resin (JET – Artigos Odontológicos Clássico) (Figure 2.B). The specimen surfaces were standardized using silicon carbide (SiC) abrasive papers (#320, #400, and #600; Buehler Ltd., Lake Bluff, IL) for 30 s each under irrigation with a polishing machine (Ecomet 3000, Buehler Ltd., Lake Bluff, IL) operating at 150 rpm. After polishing, specimens were cleaned in an ultrasonic cleaner (Shenzhen Codyson Electrical Co., Ltd.) for 10 min to remove debris.

THERMAL AGING

Specimens underwent 5,000 thermal cycles (5°C/55°C ± 3°C, 30 s per bath, 3 s transfer) (Model: 521.2.E, Ética Equipamentos Científicos S.A.) (12,32). As proposed by Gale and Darvell (33), 10,000 cycles correspond to one year of service; therefore, this protocol was chosen to simulate a six-month aging period (34).

SURFACE TREATMENTS

After thermal aging, the 150 specimens were randomly distributed according to the surface treatment (n=50): no treatment (NT), diamond bur roughening (B), and sandblasting with aluminum oxide (Al) (n=50).

ROUGHENING WITH DIAMOND BUR

Specimens were roughened for 10 s with a fine-grit diamond bur (#4138F, KG Sorensen) under water cooling, using parallel back-and-forth movements in a single plane (Figure 2.C). A new diamond bur was used after every 10 specimens. The manual pressure applied during this step was previously standardized in a pilot study for procedure consistency.

SANDBLASTING WITH AL_2O_3

Specimens were sandblasted with 50 µm Al_2O_3 using a microjet device (Standard, Bio-Art Equipamentos Odontológicos Ltda.) for 10 seconds at a distance of 10 mm from the resin surface and 60 psi, with a metal rod to standardize distance (Figure 2.D); sweeping movements were performed perpendicular to the surface.

PREPARATION OF CYLINDERS FOR MICRO-SHEAR BOND STRENGTH TEST

After surface treatments, specimens were randomly distributed (n=10) by adhesive protocol (Table 1). Prior to repair, all specimens were preconditioned with 37% phosphoric acid (Condac 37, FGM Dentscare LTDA) for 15 seconds, rinsed with air-water spray, and dried with an air spray, each for 30s. Three holes with a diameter of 1.5 mm were created in a double-sided adhesive tape (3M Manaus Indústria de Produtos Químicos Ltda.) and affixed to the surface of the resin to be repaired (Figure 2.E). The adhesive protocols were then applied within the areas delimited by holes, following the manufacturer's instructions (Figure 2. F) (Table 2).

Table 2. Instructions for applying adhesive materials.

Material	Manufacturer's instructions	Drying time	Photoactivation time
Adper Single Bond 2	Actively apply 2 coats for 15 s (each)	5 s	10 s
Single Bond Universal	Actively apply for 20 s	5 s	10 s

Subsequently, three chemically resistant silicone tube - each with an internal diameter of 1.0 mm and a height of 1.0 mm - were positioned, one over each hole in the double-sided tape (Figure 2.G). Using a double condenser #1-2 (Odous de Deus, Belo Horizonte), Filtek™ One Bulk Fill composite resin (3M ESPE, St. Paul) was inserted and condensed into the tubes (Figure 2.H). The resin was then light cured for 20 s, resulting in three composite cylinders per specimen

Specimens were stored in an oven at 37°C for 24 hours, the silicone tubes and the double-sided tape were then removed, and the adhesive interfaces were examined under a digital microscope (Dino-Lite Digital Microscope; AnMo Electronics Corp.). Specimens with interface failures were excluded from the micro-shear test.

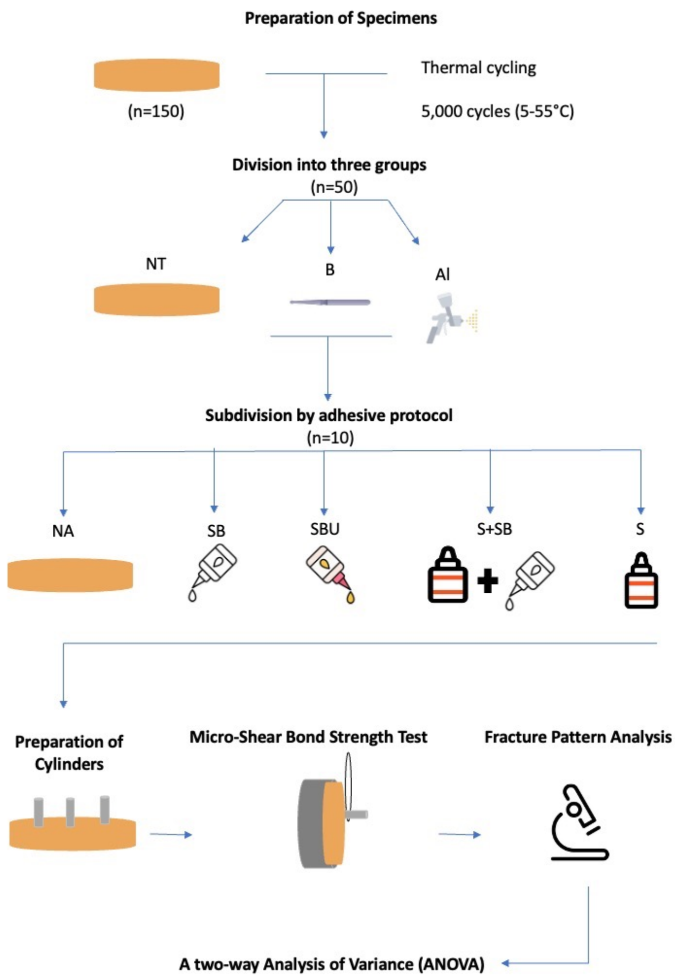

Figure 1. Work flowchart.

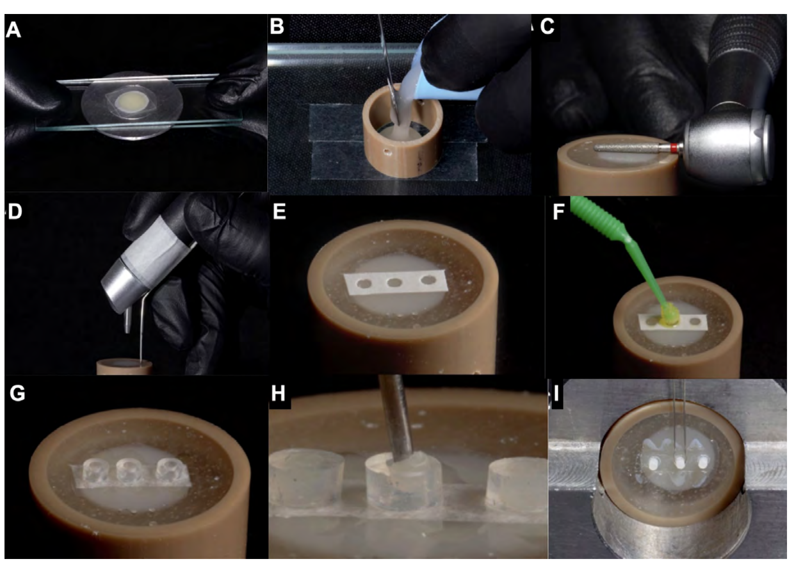

Figure 2. Representation of the step-by-step methodology presented (A-I).

BOND STRENGTH TEST – MICRO-SHEAR TEST

For the microshear bond strength test, the specimens were positioned in a universal testing machine (Instron 5942, Canton, MA, USA). A 0.25-mm diameter metallic wire was shaped into a loop and positioned so that one end encircled the resin cylinder of the specimen, remaining in intimate contact with the aged resin surface, while the other end encompassed the fixed cylinder attached to the load cell (Figure 2.I). The crosshead speed was set at 1 mm/min. At the moment of fracture, the movement was automatic and immediately interrupted.

The bond strength values were recorded in Newtons (N) and subsequently converted to Megapascals (MPa) by dividing the force (N) at the moment of fracture by the cross-sectional area of the cylinder in mm², using the formula $N/\pi r^2$.

FRACTURE PATTERN ANALYSIS

After the micro-shear test, fracture patterns were analyzed at 50× magnification using a digital microscope (Dino-Lite Digital Microscope; AnMo Electronics Corp.). Fractures was classified as Adhesive (A): when the fracture occurred only at the adhesive interface; Cohesive in aged substrate (CSE): when the fracture occurred in the structure of the aged composite resin; Cohesive in repair resin (CRR): when the fracture occurred in the repair composite resin; Mixed (M): when both adhesive and cohesive failures were observed in the aged resin or repair resin.

STATISTICAL ANALYSIS

For statistical analysis, the mean bond strength value of the three cylinders from each specimen was calculated. Two-way Analysis of Variance (ANOVA) and Tukey's post hoc test. were performed (Sigma Plot 13.0, Systat Software Inc.) with a 5% significance level.

RESULTS

BOND STRENGTH TEST – MICRO-SHEAR TEST

Both factors, surface treatment ($p<0.001$) and adhesive protocol ($p<0.001$), significantly affected the bond strength values. A significant interaction between the two factors was also observed ($p<0.001$). The means and standard deviations for all experimental groups are presented in Table 3.

The bond strength of specimens treated with diamond bur roughening or Al_2O_3 sandblasting was consistently higher than that of specimens without any prior surface treatment, regardless of the use of adhesive and/or silane.

The group sandblasted with Al_2O_3 without the use of adhesive (Al/NA) showed a higher bond strength value, with a statistically significant difference, compared to the B/NA and NT/NA groups. The mean bond strength of the groups that received diamond bur roughening (B/SB, B/SBU, B/S+SB, B/S) did not show any statistically significant difference between them and were higher than the B/NA group. Similarly, the mean bond strength of the groups that were sandblasted with Al_2O_3 (Al/SB, Al/SBU, Al/S+SB, and Al/S) did not show any statistically significant difference between them and were higher than the Al/NA group. The Al/SBU group presented the highest bond strength value, with a statistically significant difference when compared to the B/SBU and NT/SBU groups. When no surface treatment was applied, the use of an Adhesive System increased the bond strength, with the combination of the Adhesive System and Silane (NT/SBU and NT/S+SB) presenting the highest bond strength values.

FRACTURE PATTERN ANALYSIS

The percentage values of the fracture types are shown in Figure 4. Regarding the fracture pattern, only adhesive, cohesive in aged substrate, and mixed fractures were observed, with no cohesive fractures occurring in the repair resin (Figure 5).

The majority of failures in specimens without surface treatment were adhesive-type failures, except for the NT/SBU group, which exhibited more failures in the aged substrate. Most failures in the groups treated with diamond bur or Al_2O_3 sandblasting, along with the use of adhesive and/or silane, were of the mixed or cohesive type in the aged substrate. Additionally, 100% of the failures in the NT/NA, NT/SB, and NT/S groups occurred at the adhesive interface.

Table 3. Mean values (SD)± Standard deviation of micro-shear bond strength (MPa) for the studied groups.

Surface treatment	Adhesive protocol				
	No adhesive (Negative Control)	**Single Bond**	**Single Bond Universal**	**Silane + Single Bond**	**Silane**
No treatment	NT/NA	NT/SB	NT/SBU	NT/S+SB	NT/S
(Negative Control)	8,95 ± 1,83^{Cd*}	25,39 ± 4,24^{Bbc}	32,21 ± 2,73^{Ca}	28,24 ± 3,87^{Bab}	21,25 ± 5,36^{Bc}
Diamond bur	B/NA	B/SB	B/SBU	B/S+SB	B/S
	29,17 ± 3,28^{Bb}	39,75 ± 2,53^{Aa}	41,26 ± 3,75^{Ba}	40,98 ± 4,44^{Aa}	40,06 ± 2,37^{Aa}
Sandblasting with	Al/NA	Al/SB	Al/SBU	Al/S+SB	Al/S
Al_2O_3	35,4 ± 7,31^{Ab}	41,62 ± 4,17^{Aa}	45,39 ± 4,11^{Aa}	41,08 ± 3,05^{Aa}	44,05 ± 2,23^{Aa}

*Different uppercase letters indicate a statistically significant difference ($p<0.05$) in each column for the surface treatment variable. Different lowercase letters indicate a statistically significant difference ($p<0.05$) in the same row for the adhesive protocol variable.

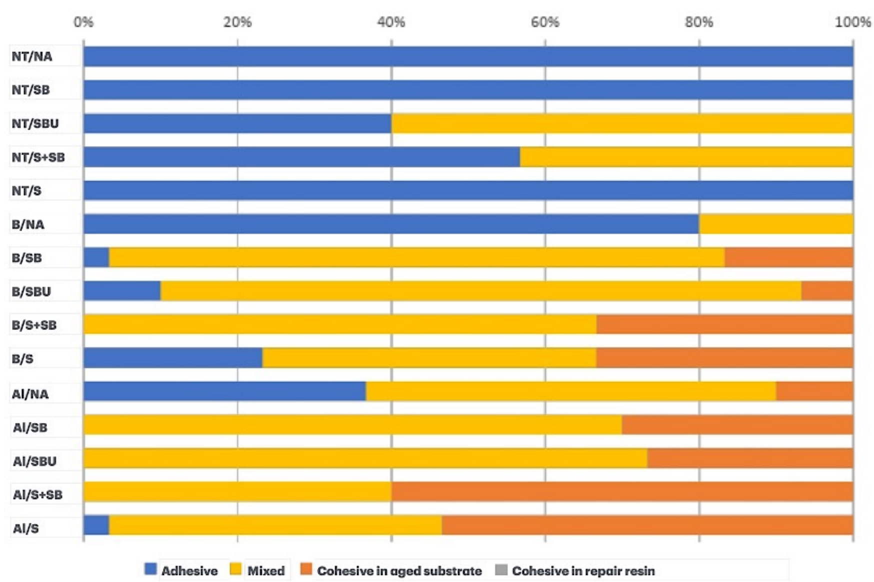

Figure 4. Percentage (%) distribution of fracture types for each studied group.

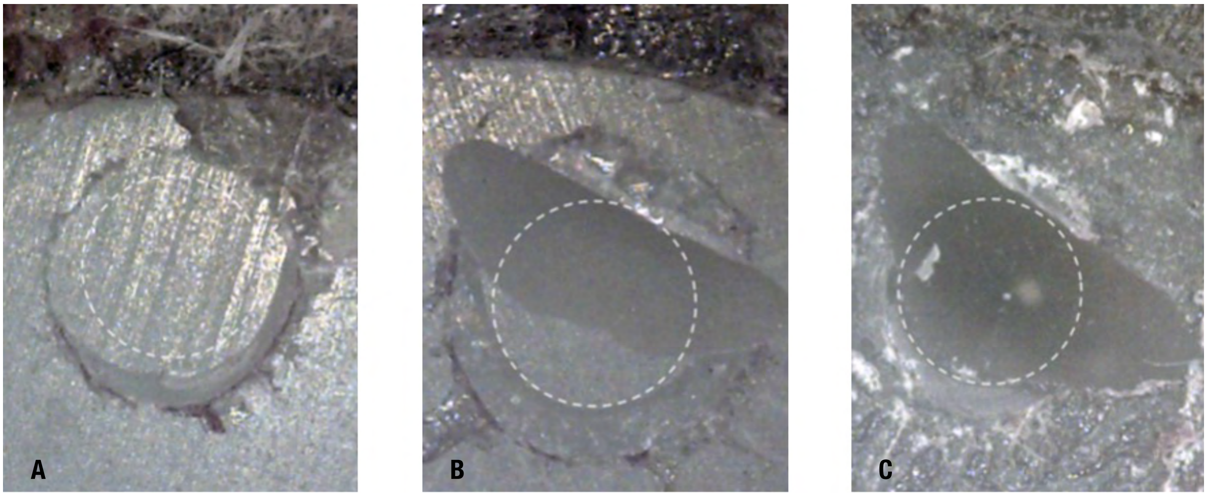

Figure 5. Appearance of the surfaces of the tested specimens, based on the possible fracture patterns. Adhesive (A); Mixed (B); Cohesive in aged substrate (C).

DISCUSSION

Based on the results obtained, the null hypotheses were rejected, as both surface treatment and adhesive protocol significantly influenced the bond strength of bulk fill resin repair.

When a restoration is repaired in the oral cavity, it is likely that it has undergone aging in a moist environment for an extended period (29). Clinically, aging results from the continuous exposure of the material to food, beverages, temperature variations, and cyclic mechanical loads. This process leads to water absorption by the resin matrix and hydrolytic degradation at the resin-filler interface, along with surface wear due to the loss of both resin matrix and filler particles (35-38). Furthermore, according to Swift Jr *et al.*, aging can cause the leaching of unreacted monomers, leading to saturation of the composite with water and the cessation of free radicals activity, thereby reducing the potential for bonding with a new repair resin (38). Consequently, aging alters the material's composition and negatively affects repair bond strength (32). Therefore, it can be assumed that when repairing an aged composite resin restoration, there is a need for prior treatment to promote a new chemical or mechanical interaction between the aged composite and the repair material.

This study evaluated the effect of two surface treatments, diamond bur roughening and Al_2O_3 sandblasting, on the bond strength of repaired composite resin. Sandblasting with Al_2O_3 particles alone significantly increased bond strength (35.4 ± 7.31 MPa) compared to both the diamond bur roughening group (29.17 ± 3.28 Mpa) and the control group (8.95 ± 1.83 MPa), which received no surface treatment. This improvement is attributed to the ability of air abrasion with Al_2O_3 particles to produce a roughened surface with microretentive features, enhancing micromechanical interloking. However, diamond bur roughening, when combined with the application of adhesive systems, demonstrated bond strength values comparable to those achieved by Al_2O_3 sandblasting (31).

According to Teixeira *et al.*, bond strength values ranging from 15 to 25 MPa, similar to those for resin-dentin bonding, are considered clinically acceptable in most cases (18). Other studies have also indicated that values above 18 MPa or within the range of 20 to 25 MPa are sufficient to withstand masticatory forces (39-41). Based on these parameters, both the group treated solely with diamond bur roughening and the group treated only with Al_2O_3 sandblasting reached the minimum adhesive strength required for clinical performance, even in the absence of silane or an adhesive system.

In addition to surface treatment, the adhesive protocol applied afterward also significantly influenced the bond strength of the repairs to aged composite resin. This is consistent with the results of previous studies (42-44) and can be attributed to the ability of adhesive systems to penetrate the microirregularities created by the mechanical surface treatment. The use of an adhesive between the aged resin and the repair resin increases the wettability of the surface as the adhesive more easily penetrates and polymerizes on the previously treated surface, creating a micromechanical retention (3,45,46). Several studies comparing repairs performed with an without adhesive application on various types of composite resin have concluded that adhesive use significantly increases bond strength in both immediate and aged composite repairs (45,47). This study, which used aged bulk fill resins, found results similar to those already found in the literature, where all groups that used adhesive presented significantly higher bond strength values for the repair of aged resin compared to groups where no adhesive was used.

In this study, the inclusion of groups without mechanical surface treatment enabled isolated evaluation of chemical treatments. In these cases, the use of a universal adhesive system containing silane resulted in a high mean bond strength value (32.21 ± 2.73 MPa), which was statistically superior to the value obtained when SB was used alone, without silane (25.39 ± 4.24 MPa). Similar results were found by Arpa et al., who observed increased bond strength when use SBU to repair CAD-CAM resin composite without any mechanical surface treatment (48). SBU contains the functional monomer MDP, which is capable of chemically bonding to zirconia oxides via a phosphate ester group (49,50), and to the resin matrix via a methacrylate group (51,52). According to the manufacturer, Filtek One Bulk Fill composite resin includes zirconia particles in addition to conventional silica fillers. Therefore, the chemical composition of the adhesive system alone can influence the repair bond strength of bulk fill resin, as demonstrated by the significantly higher mean value obtained with SBU compared to SB, which supports the observed results.

Due to its inert and highly crystalline nature, zirconia exhibits limited bonding capability with resin materials (53). Various surface treatments have been investigated to improve this interaction. The most commonly used surface treatments to increase mechanical retention to zirconia ceramic substrates are air abrasion with Al_2O_3 particles and silica coating (53-55). Air abrasion caused by sandblasting with Al_2O_3 particles creates microretentions and a uniformly rough surface, increasing the surface area that interacts with the adhesive and the new resin increment (44,56,57). In this study, sandblasting with Al_2O_3 in combination with SBU produced the highest bond strength values (45.39±4.11 MPa) compared to the B/SBU group (41.26 MPa). This outcome is likely due to a greater exposure of ceramic filler particles on the resin surface after sandblasting, increasing the available bonding area and promoting chemical bonding with the MDP present in SBU. Additionally, the low viscosity of universal adhesives increases their penetration into microscopic surface irregularities, enhancing micromechanical retention (3). However, regarding patient and professional safety, it is essential to use absolute isolation and a suction device during intraoral sandblasting, which may limit its clinical use (58).

An alternative method for abrading the surface of aged restorations prior to repair involves the use of rotary instruments. Several studies have demonstrated a significant increase in bond strength following surface treatment with diamond burs (12,22,44). Although some studies suggests that sandblasting may be more effective than roughening with a diamond bur in creating micro-retentions, these studies generally use coarse-grit diamond burs (56). However, fine-grit diamond instruments have generally shown superior performance compared to medium and extra-fine-grit instruments in terms of repair bond streght (12). In the present study, no statistically significant differences were observed between surface treatments using diamond burs and sandblasting with Al_2O_3 when combined with SB, S+SB, and silane. According to the manufacturer, the fine-grit diamond bur used in this study contains diamonds particles measuring 47µm, which is very similar to the particle size of the Al_2O_3 powder used for sandblasting (50 µm). The similarity in particle sizes may explain the comparable bond strength values observed between these groups.

Silane agents are applied prior to the adhesive system to enhance the surface wettability. Silane has two functional groups: the silanol group, which chemically bonds to the silica particles present in composite resin, and the organofunctional group, which copolymerizes with the methacrylate groups found in the adhesive systems, thus enabling a chemical interaction during the repair process (26). In the present study, silane was used alone, and when associated with prior surface treatment (groups B/S and Al/S), no statistically significant differences were found compared to the groups treated with adhesives. These results suggest that, in such conditions, silane alone can replace the functions of an adhesive as a wetting agent that fills surface irregularities in the substrate.

Previous studies have reported conflicting results regarding the effect of silane on the bond strength of composite resin repairs (11,27,56,59). In the present study, the additional application of silane prior to the adhesive did not enhance bond strength when compared to the protocol using the SB adhesive alone. However, in the groups where no surface treatment was performed, the use of SBU yielded higher bond strength values than the NT/SB group. The SBU contains pre-hydrolyzed silane, which, according to the manufacturer, remains stable for up to one year of storage (60). Additionally, no statistically significant differences were observed between the groups treated with SBU and those treated with the combined S+SB protocol, emphasizing that the presence of silane in improves bond strength only when no prior surface treatment is performed. The incorporation of silane into the universal adhesive aims to simplify bonding protocols. Therefore, the results of this study suggest that the use of SBU can simplify the adhesive protocol during the repair and eliminate the need for silane as an additional step in the repair procedure. Supporting this, a previous study that evaluate the repair of composite resins aged for three months and six years found that the application of a universal adhesive containing silane was as effective as using conventional silane followed by an adhesive system (59) corroborating the present findings.

Under clinical conditions, contamination of the surface to be repaired by saliva or moisture from the oral cavity may be inevitable and can interfere with the interaction between silane and the substrate. Consequently, performing a repair using multiple steps in the procedure may increase the risk of contamination and render the procedure more technique sensitive. In contrast, the SBU, as it contains silane in its composition and eliminates the need for silane as a separate step, may be considered less technique-sensitive and more likely to yield clinically satisfactory results.

The results indicate that groups with similar bond strength values do not necessarily exhibit the same fracture patterns. A higher incidence of adhesive fractures is associated with lower bond strength, whereas mixed and cohesive fractures in the repaired material may suggest that the adhesive bond surpassed the cohesive strength of the substrate. According to Lucena-Martín *et al*., it is possible to expect longer-lasting adhesion under masticatory forces when a composite tends to fracture cohesively (42). Therefore, the analysis of fracture patterns should be considered a relevant factor in assessing the quality of adhesion between the aged substrate and the new repair resin. A higher percentage of cohesive failures in the aged substrate was observed in the groups where silane was used in combination with surface treatment (B/S+SB, B/S, Al/S+SB, Al/S), while in the groups where only adhesives were used in combination with mechanical treatment (B/SB, B/SBU, Al/SB, Al/SBU), mixed failures were more frequent. These findings suggest that silane may enhance chemical bond to the aged substrate, thereby improving adhesion. In contrast, in groups without any surface treatment, a predominance of adhesive failures was observed, indicating weaker bonding between the materials.

Furthermore, from a clinical perspective, future studies are warranted to investigate the long-term effects of aging on the physical and chemical properties of the adhesive interface, as well its impact on the durability of adhesion when repairs are performed using bulk-fill composite resins.

CONCLUSION

Surface treatment is required when performing a bulk fill composite resin repair. When mechanical surface treatment is performed, the application of an adhesive system, whether or not combined with silane, promotes satisfactory bond strength. The use of a universal adhesive containing silane proves to be as effective as the separate application of silane followed by adhesive, and it yields superior bond strength values when applied surfaces treated with to Al_2O_3 sandblasting.

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