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BASIC RESEARCH:

# Evaluation of Different Surface Treatments on Repair Bond Strength of Aged and Non-Aged Bulk-Fill Composites

## Evaluación de diferentes tratamientos de superficie en la resistencia de unión de reparación de resinas compuestas tipo bulk-fill envejecidas y no envejecidas

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ABSTRACT: The aim of this study was to evaluate the effect of surface treatment and ageing on the microtensile bond strength of bulk fill composite repairs. Composite blocks were prepared using a bulk fill resin composite and divided into two groups: (A) no ageing and (B) ageing. The composite surfaces were conditioned with: (G1) control group (no surface treatment), (G2) adhesive application, (G3) phosphoric acid etching + adhesive application, (G4) phosphoric acid etching + silane + adhesive application, (G5) hydrofluoric acid etching + adhesive application, (G6) hydrofluoric acid etching + silane + adhesive application, (G7) aluminium oxide (Al2O3) sandblasting + adhesive application, (G8) Al2O3 sandblasting + silane + adhesive application. Bulk-fill substrates were then repaired with resin composite. Repaired resin blocks were cut into sticks and subjected to a microtensile test. Mechanically treated surfaces were characterized by SEM and profilometry. The highest microtensile bond strength values were obtained in group 1A. Al2O3 sandblasting followed by silane and adhesive application significantly improved microtensile bond strength values from the other ageing groups. The repair bond strength of thermal-aged bulk-fill composites is lower than non-aged composites. Silane application increased the microtensile bond strength.

KEYWORDS: Ageing; Microtensile bond strength; Resin composite; Repair; Surface treatment.

RESUMEN: El objetivo de este estudio fue evaluar el efecto del tratamiento de superficie y el envejecimiento en la resistencia de unión por microtracción de las reparaciones de resina compuesta tipo bulk-fill. Se prepararon bloques de resina utilizando una resina compuesta tipo bulk-fill y se dividieron en dos grupos: (A) sin envejecimiento y (B) con envejecimiento. Las superficies de resina se acondicionaron mediante los siguientes procedimientos: (G1) grupo control (sin tratamiento de superficie), (G2) aplicación de adhesivo, (G3) grabado con ácido fosfórico + aplicación de adhesivo, (G4) grabado con ácido fosfórico + silano + aplicación de adhesivo, (G5) grabado con ácido fluorhídrico + aplicación de adhesivo, (G6) grabado con ácido fluorhídrico + silano + aplicación de adhesivo, (G7) arenado con óxido de aluminio (Al2O3) + aplicación de adhesivo, (G8) arenado con Al2O3 + silano + aplicación de adhesivo. Posteriormente, los sustratos bulk-fill se sometieron a un proceso de reparación utilizando resina compuesta. Los bloques de resina reparados se cortaron en barras y se sometieron a una prueba de microtracción. Las superficies tratadas mecánicamente se caracterizaron mediante microscopía electrónica de barrido (MEB) y profilometría. Los valores más altos de resistencia de unión por microtracción se obtuvieron en el grupo 1A. El arenado con Al2O3 seguido de la aplicación de silano y adhesivo mejoró significativamente los valores de resistencia de unión por microtracción en comparación con los otros grupos envejecidos. La resistencia de unión de reparación de las resinas compuestas tipo bulk-fill con envejecimiento térmico es menor que la de las resinas sin envejecimiento. La aplicación de silano aumentó la resistencia de unión por microtracción.

PALABRAS CLAVE: Envejecimiento; Resistencia de la unión microtensil; Resina compuesta; Reparación; Tratamiento de superficie.

## INTRODUCTION

Today, composite resins are routinely used in dentistry because of their esthetic and adhesive properties and their ability to preserve sound tooth structure. However, changes in temperature and pH in the oral environment, diet, and other factors can cause composites to degrade over time (1). Degradation may lead to failures such as microleakage, abrasion, fracture, discoloration and secondary caries in composite restorations (2). In such cases, it is not always necessary or desirable to completely replace the old restoration (3). This procedure can damage the intact tooth tissue and require larger cavity preparation, even resulting in the exposure of the pulp (4). In addition, the repair of a restoration offers a good cost–benefit ratio for the patient (5).In this context, repairing the restorations is a more protective method rather than replacing the whole restoration since it is both a conservative procedure and reduces the time required for treatment.

The success of the repair process depends on the bond strength of old and new composites. In clinical practice, the bond between old and new composite layers is achieved by the presence of an oxygen-rich surface layer that remains unpolymerized. This "oxygen inhibition layer" contains unreacted monomers and double carbon bonds (C=C) that allow new composite resin monomers to bond (6, 7). Monomers containing double bonds that form these reactive groups that will chemically bond to the new composite layer decrease after polymerization depending on the time. However, as the composite restoration ages, the oxygen inhibition layer and free radicals on the surface disappear and water absorption occurs. This reduces the repair bond strength between the old and new composite layers (8).

Mechanical and chemical surface treatments are applied to the composite surface to improve repair bond strength by increasing the wettability and surface area (9). The most commonly used method for this purpose is the application of silanes and adhesives to help achieve chemical bonding, followed by the roughening of the surface by mechanical preparation (10). Various surface preparation methods such as applying hydrofluoric (HF) or phosphoric ($H3PO4$) acid, air abrasion with aluminum oxide ($Al2O3$) particles, adhesive application, silane application are used to increase the repair bond strength of composite resins (3).

In order to reduce the time and workload required for layering of conventional composites and to allow for better adaptation of composites in the posterior region; bulk-fill composites have been developed that can be applied in a single layer. Manufacturers claim that these materials have a polymerization depth of 4-5 mm.

Although there are many *in vitro* studies in the literature on the effect of different surface treatment methods on the repair bond strength of conventional composite restorations (11, 12), there are very few studies on the repair of bulk-fill composites. It is important to consider whether the different properties of these materials affect the reparability compared to conventional composites. Since the tools and methods used in all these studies are different, there is no clear information on which repair method provides the most successful clinical results.

The purpose of the present study was to evaluate the effect of aging and different surface treatment methods on the microtensile bond strength (µTBS) of bulk fill composite repairs using a universal adhesive system, and to examine fracture types, surface morphologies, and roughness.

The first null hypothesis tested was that different surface treatment methods have no effect on the repair µTBS of bulk fill composite resin. The second null hypothesis tested was that different surface treatment methods have no effect on the repair µTBS of aged bulk fill composite resin.

## MATERIALS AND METHODS

The sample size for each group (n=20) was determined based on similar previous studies. A post-hoc power analysis was conducted using G*Power software (v3.1.9.7). For a one-way ANOVA, with a significance level of $\alpha = 0.05$ and a large effect size ($f = 0.40$), the calculated power ($1-\beta$) of the study was 0.96. This indicates that the sample size was sufficient to detect significant differences between the groups with high statistical confidence.

### SPECIMEN PREPARATION

The materials used in the study and their properties are shown in Table 1. A silicone mold was used to fabricate 32 blocks (8×8×4 mm) of SonicFill 2 (Kerr Corp., Orange, CA, USA) bulk fill composite. All specimens were polymerized from the bottom and top for a total of 40 seconds using an LED curing device (Valo, Ultradent, UT, USA) for 20 seconds. The composite blocks were divided into 2 main groups, non-aged (A) and aged (B). Non-aged group (A): For fresh specimens, repair in 5 minutes after the final polymerization.  Aged group (B): Samples in this group were aged using a thermocycling machine (TPO4, Delta, Turkey) with 10.000 cycles to simulate 1-year clinical use.

Temperatures were between 5 and 55 °C with a dwell time of 30 s in each bath.

The following surface treatments were applied to the composite surfaces prior to the repair process. The specimens were divided into 8 subgroups according to the surface treatment.

Group 1: Control group (no surface treatment).

Group 2: Adhesive application only (G-Premio Universal Bond, GC Corp., Tokyo, Japan was applied and polymerized according to the manufacturer’s instructions).

Group 3: H3PO4 etching followed by adhesive application; 37% H3PO4 (Condac 37 FGM, Joinville, SC, Brazil) was applied the composite surface for 20 seconds then G-Premio Bond was applied and polymerized).

Group 4: H3PO4 etching followed by silane and adhesive application; 37% H3PO4 was applied to the composite surface for 20 seconds. A thin layer of silane (Ultradent Products Inc., South Jordan, UT, USA) was applied according to the manufacturer's instructions, allowed to set for 1 minute and dried with air spray for 5 seconds. The G-Premio Bond was applied and polymerized.

Group 5: HF etching followed by adhesive application; the composite surface was etched with %9 HF (Ultradent Products Inc., South Jordan, UT, USA) for 20 seconds then G-Premio Bond was applied and polymerized.

Group 6: HF etching followed by silane and adhesive application; %9 HF was applied to the composite surface for 20 seconds. Silane was then applied to the composite surface. The G-Premio Bond was applied and polymerized.

Group 7: Al2O3 sandblasting followed by adhesive application; The composite surface was roughened with a sandblasting machine (Air Max, Satelec Acteon, Merignac, France) using 50 µm Al2O3 powder under 2.5 bar air pressure for 5 seconds at a distance of 5 mm from the composite surface. G-Premio Bond was then applied and polymerized.

Group 8: Al2O3 sandblasting followed by silane and adhesive application; Al2O3 was applied to the composite surface as in the previous group. Silane and G-Premio Bond was then applied to the surface.

The composite blocks with different surface treatments were repaired with a nanohybrid composite resin (Ceram X, Dentsply, DeTrey, Konstanz, Germany) in dimensions of 8×8×4 mm according to the manufacturer's instructions.

All samples were stored in distilled water at 37°C for 24 hours during the process of obtaining composite sticks for the µTBS test. The flow chart of the study design is shown in Figure 1.

**Table 1**. Materials used in this study.

| | Material | Manufacturer | Composition |
|---|---|---|---|
| Adhesive System | G-Premio Universal Bond | GC Corp., Tokyo, Japan | 10-MDP, 4-MET, MTDP, methacrylic acid ester, silica, acetone, water, photo initiators |
| Composite Resins | SonicFill 2 Bulk-fill | Kerr Corp., Orange. CA, USA | Dimethacrylates, BisGMA, Bis EMA, silica barium glass, YbF3, mixed oxides |
| | Ceram X | Dentsply, DeTrey, Konstanz, Germany | Bis-GMA, UDMA, TEGDMA, methacrylate modified polysiloxane, barium-aluminium-borosilicate glass, iron oxide and titanium oxide, aluminium sulfo-silicate pigments |
| Silane | Ultradent | Ultradent Products Inc., USA | 5-15% methacryloxypropyl-trimethoxysilane, 92% 2-propanol |

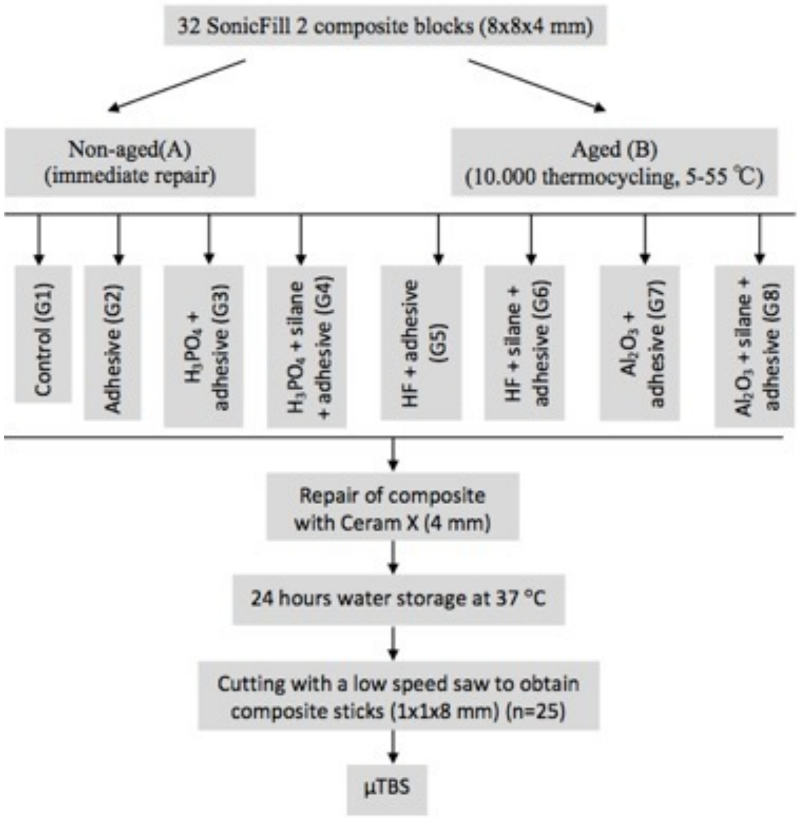

**Figure 1**. Flowchart of study design. (H3PO4: phosphoric acid, HF: hydrofluoric acid, Al2O3: aluminium oxide, µTBS: microtensile bond strength).

### MICRO TENSILE BOND STRENGTH TEST (ΜTBS)

First, repaired composite blocks were fixed to a cutting machine (Isomet, Buehler, Düsseldorf, Germany) and cut into sticks (1x1x8 mm) with a low-speed diamond saw under water cooling.

Twenty-five composite sticks were obtained from each group for µTBS testing (n=25).

Before attaching the specimens to the test apparatus of the micro tensile tester (Micro Tensile Tester, Bisco, USA) with cyanoacrylate adhesive, the dimensions of the specimens were measured with a digital caliper (Mitutoyo Digital Caliper, Mitutoyo Co., Kanagawa, Japan). The µTBS test was applied to composite sticks at a head speed of 1 mm/min until failure occurred. The tensile load at which the failure occurred was recorded in Newtons and then converted to megapascals (MPa).

### FRACTURE PATTERN ANALYSIS

The fractured surfaces of the specimens were examined at ×25 magnification under a stereomicroscope (Zeiss, Jena, Germany) to determine the fracture type. The fracture types were classified as follows; Adhesive: Failure at the adhesive surface, Mix: Mix failure at adhesive surface and composite resin, Cohesive: Failure in the composite resin.

### SURFACE ROUGHNESS ANALYSIS

For the surface roughness analysis of both the aged and non-aged groups, a total of 48 disk-shaped samples (5 mm diameter, 2 mm height) were prepared from the control group, phosphoric acid and hydrofluoric acid etched groups and sandblasted group (n=6). A portable contact roughness tester (Surftest SJ-201P, Mitutoyo, Tokyo, Japan) was used to measure the amplitude parameter Ra (mm). The following test conditions were used: cut-off length 0.25 mm, resolution 0.0001 mm (8 mm range), speed 0.5 mm/s, and total length 4 mm. For each specimen, three measurements were taken on the x-axis and three on the y-axis. The average of these measurements was used in the analysis.

### SCANNING ELECTRON MICROSCOPY (SEM) ANALYSIS

For the SEM evaluation, one sample from each group, which were used for surface roughness analysis, was randomly selected. The samples were coated with a gold-palladium (Au-Pd) layer prior to imaging. Surface analyses were performed by SEM (FEI QUANTA 400F Field Emission, FEI Company, USA) at ×1000 magnifications.

### STATISTICAL ANALYSIS

In this study, statistical analyses were performed using the SPSS 22 program (IBM Corp., Armonk, NY, USA). The Kolmogorov-Smirnov and Shapiro-Wilk tests were performed to verify the normality of the distribution of bond strength and surface roughness values within the different groups. As a test results, One-way analysis of variance (ANOVA) and Tukey HSD test analysis were used to evaluate the differences between groups. Independent groups t-test was used for comparisons between groups. The significance level was set at $p = 0.05$ for all data.

## RESULTS

The mean bond strength and standard deviation values (MPa) of all groups of our study ARE shown in Table 2 and Figure 2. The pre-test failure occurred during the cutting process in the 1B group specimens. This group is not included in the µTBS calculations. The highest bond strength value was observed in the non-aged control group (1A) (46.87 MPa). The lowest bond strength value was seen in the aged HF and adhesive applied (5B) group (24.39 MPa). It was found that silane application on aged samples roughened with H3PO4, HF and Al2O3 significantly increased the bond strength compared to the non-silane group (p <0.05). In the samples of the non-aged group, silane application showed a significant difference (p<0.05) only in the Al2O3 roughened group (7A-8A). Group 8B, Al2O3, silane and adhesive applied group showed significantly higher repair bond strength value than all other aged samples. All specimens in aged groups showed statistically significant lower (p<0.05) bond strength values than the specimens in groups that were not aged.

The data of fracture patterns are shown in Table 3. The most common type of failure was adhesive failure (57%) in all groups, it was followed by cohesive failure (35.25%). The least common type of failure is mix failure (1.5%).

The ΔRa values of non-aged and aged composite surfaces after H3PO4, HF and Al2O3 applications are shown in Figure 3.

Al2O3 applications showed significantly higher ΔRa value than H3PO4 and HF applications (p<0.05). SEM analysis revealed different surface topography (Figure 4) of the surface-treated bulk-fill composite. Al2O3 sandblasting produced significant surface irregularities, which could be supported by the highest microtensile bond strength. There was no difference between the SEM images of the FA and HF groups according to the surface roughness values.

**Table 2**. Mean and standard deviation values of micro tensile bond strength test results (MPa).

| Groups | Surface Treatments | A<br>(Non-aged) | | B<br>(Aged) | |
|---|---|---|---|---|---|
| 1 | Control | $46.87 \pm 8.63^{b}$ | | - | |
| 2 | Adhesive | $41.34 \pm 7.94^{ab}$ | | $25.51 \pm 4.08^{xy}$ | |
| 3 | $H_3PO_4$ +Adhesive | $39.44 \pm 9.26^{a}$ | | $28.63 \pm 3.50^{yz}$ | ] |
| 4 | $H_3PO_4$ + Silane + Adhesive | $39.52 \pm 8.89^{a}$ | | $30.82 \pm 3.47^{z}$ | |
| 5 | HF +Adhesive | $41.69 \pm 5.96^{ab}$ | | $24.39 \pm 3.89^{x}$ | ] |
| 6 | HF +Silane+Adhesive | $39.89 \pm 6.15^{a}$ | | $30.57 \pm 5.54^{z}$ | |
| 7 | $Al_2O_3$ +Adhesive | $40.86 \pm 3.62^{ab}$ | ] | $30.70 \pm 4.59^{z}$ | ] |
| 8 | $Al_2O_3$ + Silane + Adhesive | $44.28 \pm 5.12^{ab}$ | | $36.12 \pm 6.49^{w}$ | |

According to one-way analysis of variance and Tukey HSD results, different lower-case letters in each column show statistically different groups. (p<0,05). Independent groups t-test was conducted to determine the differences between the groups treated with silane. The ] sign indicates a statistically significant difference between two groups. (p<0.05)

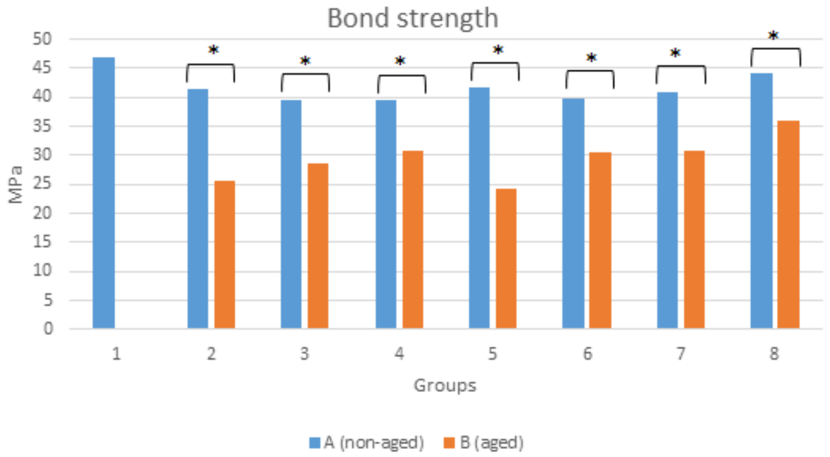

**Figure 2**. Mean values of micro tensile bond strength test results (MPa) Independent groups t-test was performed to determine the differences between groups A (non-aged) and B (aged). The * sign indicates a statistically significant difference. ($p<0.05$).

**Table 3**. Numerical distribution of fracture types in µTBS test samples.

| Groups | | Pre-test Failure | Adhesive | Mix | Cohesive |
|---|---|---|---|---|---|
| Non-Aged | 1 | 0 | 10 | 1 | 14 |
| | 2 | 0 | 10 | 3 | 12 |
| | 3 | 0 | 7 | 0 | 18 |
| | 4 | 0 | 12 | 1 | 12 |
| | 5 | 0 | 19 | 1 | 5 |
| | 6 | 0 | 12 | 0 | 13 |
| | 7 | 0 | 15 | 0 | 10 |
| | 8 | 0 | 8 | 0 | 17 |
| Aged | 1 | 25 | 0 | 0 | 0 |
| | 2 | 0 | 23 | 0 | 2 |
| | 3 | 0 | 20 | 0 | 5 |
| | 4 | 0 | 18 | 0 | 7 |
| | 5 | 0 | 23 | 0 | 2 |
| | 6 | 0 | 20 | 0 | 5 |
| | 7 | 0 | 18 | 0 | 7 |
| | 8 | 0 | 13 | 1 | 11 |
| | Total | 25<br>(6.25%) | 228<br>(57%) | 6<br>(1.5%) | 141<br>(35.25%) |

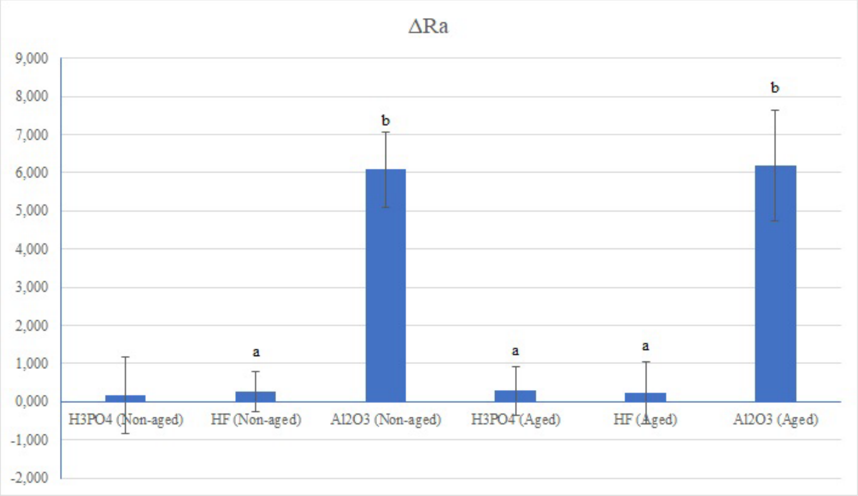

**Figure 3**. Mean and standard deviation values of ΔRa.

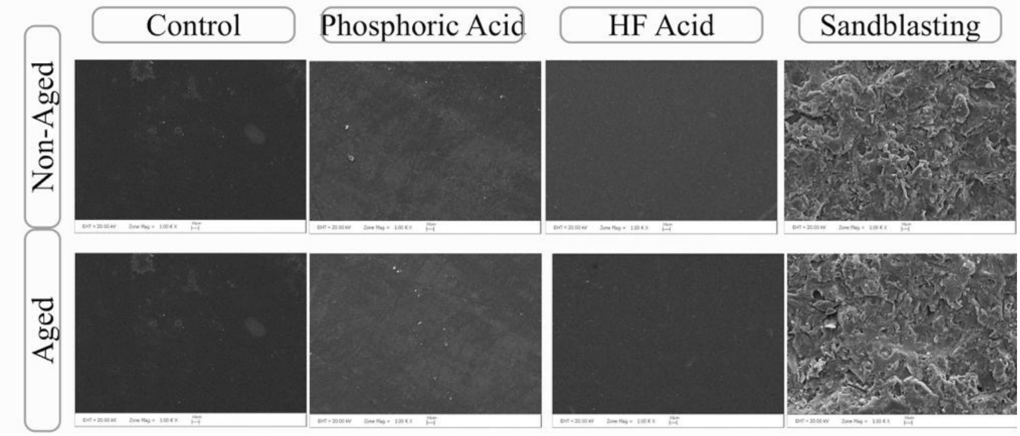

**Figure 4**. SEM micrographs of the non-aged and aged SonicFill bulk-fill composite surfaces after different surface treatments.

## DISCUSSION

Composite resins are routinely used in dental restorations. However, composite resins have a limited clinical lifetime and have an average annual failure rate of %1.7 (13). In such cases, instead of replacing the restoration, if only a certain part of the restoration is damaged and the remaining part is intact, repairing the restoration is more conservative and a short-term treatment option. As a result of the previous studies, it has been shown that the restoration repair prolongs the life of the tooth to a clinically acceptable level (14, 15). Kanzow *et al*. concluded that restoration repair is an appropriate treatment to improve the survival of restorations and is even comparable to restoration replacement (16).

For composite restorations, repairs are typically required months or years after the restoration is made. During the aging process of composite resins, various changes occur that can affect the success of the repair process such as water absorption, chemical degradation, and release of some components (17, 18). Therefore, the age of the composite restoration plays an important role in the bond strength of the repair. Rosales-Leal, JI. (19) reported that thermocycling is a simple aging method and can simulate thermal stresses that may occur in the oral environment. Many studies have reported that aging groups have significantly lower repair bond strength (17, 18, 20, 21). When the results of the present study were examined without considering the effect of different surface treatment methods, it was found that repairing the composite resin aged with thermocycling significantly reduced the μTBS values. In addition, more adhesive failures were reported when the fracture modes of aged specimens were examined. Therefore, the first null hypothesis was rejected.

The success of the repair process depends on an acceptable level of bonding between the old and the new resin composite. Generally, the bond between two composite layers is provided by the oxygen inhibition layer caused by unreacted monomers (22). These unreacted monomers provide adhesion between composite layers applied in the same appointment. In this study, the highest bond strength values (46.87 MPa) of the non-aged control group (1A) can be explained by this situation. However, as the composite restoration ages, the oxygen inhibited layer and free radicals on the surface are lost and water absorption occurs, making it difficult for the new composite to adequately bond to the old composite. It is believed that the pretest failure occurred because the number of unreacted monomers that would allow bonding on the surface of the aged control group (1B) composites decreased, water absorption occurred, and no surface treatment was performed to ensure bonding. This problem may be solved by applying a mechanical surface treatment such as $H_3PO_4$ or HF acid roughening, application of air-abrasive abrasive particles to repair old restorations, create macro and micro retention areas and increase the exposure of the resin matrix and inorganic filler particles (23). In addition to a mechanical surface treatment, it is also necessary to apply chemical treatments such as adhesive and silane application which work by bonding with the organic matrix and the exposed filler particles (24). Previous studies have reported that surface roughness is more effective on bond strength than adhesive or silane application (25, 26). In a study by Kanzow *et al*. (27), repair of aged composites with 10.000 thermocycles, only the universal adhesive applied group without any surface treatment determined significantly lower shear bond strength values than the other surface treatment groups. In another study by Şişmanoğlu S. (28), among the aged composites with 5.000 thermocycles, the universal adhesive applied group without any roughening showed a significantly lower bond strength value than the roughened groups. In this study, only the adhesive-applied group (2B) showed lower repair bond strength values than the other aged groups. Considering the results of the previous studies, the application of adhesive alone on aged composites without applying a mechanical surface treatment does not provide the optimum repair bond strength. It is also recommended to apply silane after roughening the surface if the composite is to be repaired (29, 30). Michelotti *et al*. (31), reported that the use of silane with a conventional adhesive system resulted in higher bond strength values than a universal adhesive applied without prior silanization. Souza *et al*. (20), showed that silane application after sandblasting with $Al_2O_3$ resulted in significantly higher bond strength value. Other studies such as these have shown that the application of silane can increase the repair bond strength between old and new composites (32-35). In this study, it was concluded that silane application statistically increased ($p<0.05$) the repair bond strength in the aged groups applied phosphoric acid, hydrofluoric acid, and sandblasting (3B-4B, 5B-6B and 7B-8B) and in the non-aged sandblasted group (7A-8A). Finally, it should be noted that the use of silane plays an important role in repair bond strength. Acid etching of composite surfaces is usually performed with phosphoric acid or hydrofluoric acid. Phosphoric acid is effective on enamel and dentin but has no direct effect on the surface properties of composites, ceramics, and metals. However, etching has a beneficial effect on retention rates after repair due to its cleaning and degreasing effect on these surfaces (36).

On the other hand, Donova *et al*. (37) reported that phosphoric acid application improved bond strength on immediately contaminated composite surfaces. In contrast to this study, the present study found that phosphoric acid etching did not show a significant difference between the contaminated and non-contaminated groups in the present study. The bond strength of the phosphoric acid followed by adhesive applied groups (3A-3B) was not statistically different from the adhesive only applied groups (2A-2B). Unlike phosphoric acid, hydrofluoric acid affects the glass particles in the ceramic and does not affect the resin matrix in most composites. Although the composite used in this study contains barium glass filler, the HF application did not affect bond strength. It has been reported that the application time of HF acid also affects bond strength. Loomans *et al*. (36) reported that 9% HF acid did not significantly increase bond strength when applied for 20 seconds, whereas composite repair significantly increased bond strength when applied for 120 seconds. In addition to its use in many areas of dentistry, sandblasting is also recommended for cleaning and roughening the surface prior to restoration repair (38). Atalay *et al*. (39) showed that roughening the bulk fill composite surface by sandblasting resulted in higher bond strength values than phosphoric acid. In a previous study, it was reported that sandblasting followed by silane application showed higher bond strength values in 1-year-old composite compared to the control group (20). Fornazari *et al*. (25) showed that the specimens, which were abraded by sandblasting followed by silane and adhesive application, had the highest repair bond strength. According to the results of the present study, the 8B group in which sandblasting followed by silane and adhesive were applied together showed the highest μTBS value (36.12 MPa) in the aged composite group. Regarding the chemical etching methods used in our study, the relatively lower performance of hydrofluoric acid (HF) compared to sandblasting can be attributed to its selective action. The chemical effect of HF on composites is restricted to the inorganic phase; it creates voids by selectively dissolving glass filler particles but leaves the resin matrix intact.(21) This 'filler-stripping' effect may lead to a mismatch in micro-mechanical interlocking and potentially weaken the superficial layer of the aged composite (34), unlike the more uniform and high-energy surface created by Al2O3 sandblasting.

The results of this study showed that different surface treatments can produce different results on the composite surface. It was noted that the application of phosphoric acid, which has a cleaning effect on the surface, did not significantly increase the roughness value as expected. Etching with hydrofluoric acid depends on the content of the composite and the application time. In a previous study, when 9% HF was applied for 20 seconds and 120 seconds, a relatively small increase was measured at 20 seconds compared to the control group, while a significant increase was found at 120 seconds (36). The fact that HF application did not show a significant difference in roughness in the current study may be explained by the 20-second application. Sandblasting showed a significant difference in surface roughness compared to acid applications. However, SEM images also showed significant surface defects after sandblasting. In this study, it can be said that different surface treatments show different bond strength values when aging is not considered. Therefore, the second null hypothesis that different surface treatment methods have no effect on μTBS in the repair process was also rejected.

In the present study, only bulk-fill composite was used as the restorative material and only a universal adhesive was used as the adhesive system. In addition, the specimens were aged using only the thermal cycling method. Although thermal cycling is the most preferred method of aging in the laboratory environment, teeth are exposed to not only thermal but also to mechanical and chemical effects in the oral environment. However, for the results to be applicable to more clinical situations, more *in vitro* studies testing different composite resin and adhesive systems are needed and the results should be supported by in vivo studies. Within the limitations of this in vitro study, the following results can be concluded:

1. When a contamination-free repair is required in a bulk-fill composite restoration, it has been determined that it is sufficient to repair without any surface treatment.

2. Thermal aging of bulk-fill composite specimens resulted in significantly reduced repair bond strength values.

3. Sandblasting with Al2O3 followed by application of silane and adhesive for bulk-fill repair process showed significantly higher bond strength values after thermal aging.

4. It was concluded that the use of a silane prior to the application of the adhesive increased the bond strength of bulk fill composite repairs.

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AUTHOR CONTRIBUTION STATEMENT: Conceptualization and Design, A.D. and K.Y.; Literature Review, A.D. and K.Y.; Methodology and Validation, A.D. and K.Y.; Formal Analysis, Ç.B.; Investigation and Data Collection, K.Y.; Resources, A.D. and Ç.B.; Data Analysis and Interpretation, Ç.B.; Writing – Original Draft Preparation, AD. and K.Y.; Writing – Review & Editing, A.D, K.Y. and ÇB; Supervision, A.D.; Project Administration, A.D.

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