Effect of Organic Solvents Compared to Sandblasting on the Repair Bond Strength of Nanohybrid and Nanofilled Composite Resins

Abstract

Background: This study evaluated the effect of different surface treatments on the repair bond strength of nanohybrid (Empress Direct) and nanofilled (Filtex 2350 XT) composite resins. Materials and Methods: A total of 120 specimens of each material (7.5 x 4.5 x 3 mm) were prepared and polished with SiC paper. Half of the specimens were kept in water for seven days and the other half for six months; they were then divided into six groups according to the type of surface treatment: negative control (no treatment), Al₂O₃ sandblasted, liquid aceton, acetone gel, liquid alcohol and alcohol gel. Following application of the silane coupling agent and the adhesive system, composite resin cylinders were fabricated on the specimens and light cured (20 seconds). The same composite resins were used for the repair. Additionally, ten intact specimens of each composite resin (without repair) were prepared (positive control). The specimens were then loaded to failure in the microshear mode. Three additional specimens were fabricated in each group, and the surface treatments were analyzed by atomic force microscopy, energy-dispersive X-ray spectroscopy (EDS) and scanning electron microscopy (SEM). Results: The nanofilled composite resin showed higher cohesive strength and repair bond strength than the nanohybrid composite resin. The aging process affected the repair bond strength of the nanofilled composite resin. Al₂O₃ sandblasting was more efficient for the nanofilled composite resin and promoted greater surface roughness in both materials. The solvents demonstrated higher efficacy for the nanohybrid composite resin. Conclusion: The strengths resulting from the solvents were material dependent, and Al₂O₃ sandblasting resulted in superior repair bond strength in both materials.

Keywords: Composite resin, microshear bond-strength, repair, solvent, surface treatment

Introduction

The use of composite resins in dentistry has become routine because of their esthetic, adhesive, and technical advantages, allowing the conservation of healthy tooth structure. However, the conditions of the oral environment, including variations in temperature, pH changes, diet and other factors, can degrade the composites. The in vivo degradation of these materials can lead to restoration discoloration, marginal discoloration, wear, and fractures.

In many cases, composite restorations that have minor defects do not require complete replacement. In these situations, repair with a new layer of composite resin can prevent further loss of the intact tooth structure. However, the correct indication for the repair procedure must be considered. Clinical problems, such as small fractures, marginal discoloration, loss of anatomic contour, extrinsic stains, and incorrect color and shape, can be resolved with this conservative procedure.

The success of the repair procedure with composite resin depends on factors such as the surface condition of the composite resin, chemical composition, roughness, wettability and surface conditioning methods. The aging of the composite surface in the oral environment decreases the bond strength between the composite resin layers to approximately 25%–80% of the original strength. Several surface treatments have been developed to improve resin-to-resin adhesion. According to the recent studies, methods that promote micromechanical retention also promote higher bond strength for the repair procedure. Sandblasting with aluminum oxide (Al₂O₃) and roughening with diamond burs are examples of these methods. The use of an adhesive system between the old and new resin promotes greater wettability on the surface to be repaired. Because of its low viscosity, the adhesive penetrates...
and polymerizes in the areas of microretention, increasing the bond strength.\[8,9\]

The requirement of using a silane coupling agent in the composite resin repair procedure is based on the inorganic composition of the composite resin to be repaired. Several studies have shown that when the inorganic phase of the composite resin contains silica-based components, silane application provides better bond strength because of the chemical bond between the inorganic particles of the old composite resin and the adhesive system or organic matrix of the new repair composite resin.\[6,8,9,11\]

Currently, nanohybrid and nanofiller composite resins are commonly used in esthetic restorations. The former contain filler particles with sizes from 0.4 to 1.4 μm while the latter contain particles approximately 5–75 nm in size.\[12\]

The types of monomers in the composition of resinous materials are crucial in facing surface treatments with solvents. The organic composition and varying amounts of each monomer can lead to different facing behaviors from the use of solubilizing solvents such as acetone and alcohol.\[13\]

Solvents are substances that are capable of dissolving or dispersing other substances by separating their molecules and occupying the intermolecular spaces.\[14\] The degree of solubilization of the solvents is determined by their polarity. Polar solids are dissolved with polar solvents, and nonpolar solids are dissolved with nonpolar solvents.\[14\] Acetone and alcohol are solvents that possess the appropriate characteristics for use with organic components.\[14\] The previous studies have reported that solvents open the polymer chains of the surface to be repaired, thus causing an imbrication between the old acrylic resin and the repair acrylic resin.\[15,16,17\] Nevertheless, the effect of solvents in composite resin repair has not been evaluated.

The aims of this study are to evaluate the effect of solvents on the repair bond strength of two composite resins (nanohybrid and nanofilled), their influence on surface morphology, and the resultant chemical changes at the resin surface. The study hypothesis is that surface treatment with solvents can promote repair bond strengths that are comparable to cohesive composite resin strengths.

**Materials and Methods**

**Specimens for the microshear bond strength test**

A total of 120 conical specimens were fabricated (7.5 mm top diameter and 4.5 mm bottom diameter × 3 mm thickness) for each composite resin: the nanofilled composite resin Filtek Z350 XT (3M ESPE, St. Paul, MN, USA; color: A2 enamel; batch: 110 280 09; organic composition: BIS-GMA, UDMA, TEGDMA, PEGDMA, and BIS-EMA; inorganic composition: 20 nm silica, zirconia 4–11 nm, and agglomerates with an average size from 0.6 to 20 nm, 72.5% by weight) and the nanohybrid composite resin Empress Direct (Ivoclar Vivadent, Schaan, Liechtenstein; color: A2E; batch: N21727; organic composition: BIS-GMA, UDMA, and TEGDMA; inorganic composition: barium glass, ytterbium trifluoride, mixed oxide, silicon dioxide, and copolymer of between 40 nm and 3000 nm with an average size of 550 nm, 75%–79% by weight). The specimens were produced using a metal mold covered with plastic strips between two glass slabs to promote a smooth surface. The composites were inserted in two increments and cured according to the manufacturer’s instructions. Each increment was light cured for 20 s with a blue phase light emitting diode (LED) light-curing unit (Ivoclar Vivadent, Schaan, Liechtenstein) with an irradiance of 650 mW/cm², which was measured using a radiometer before and during the fabrication of the specimens. The specimens were embedded in a clear autopolymerizing acrylic resin (JET, Articles Dental Classic, São Paulo, SP, Brazil) using a PVC mold that exposed only the surface to be tested. All specimens were ground sequentially on one side with 400, 600, 1000 and 1200 grit wet silicon paper (3M, Sumaré, SP, Brazil) under abundant water cooling. Half of the samples of each resin were immersed in water at 37°C for 6 months to simulate the aging process. Water changes were performed weekly. The other half were immersed in water at 37°C for 7 days. The specimens treated for both time periods were randomly divided into six groups for the surface treatments described in Table 1.

After each surface treatment, adhesive tape with a central hole of 1.2 mm diameter was placed on the specimens to delimitate the application area of the adhesive. This procedure ensured that the area to which the adhesive was applied was limited to the inside of the circular hole, preventing an excess of adhesive beyond the edge of the bond area, which could lead to artificially high-bond strength values. The silane coupling agent Monobond Plus (Ivoclar Vivadent, Schaan, Liechtenstein) was applied with a disposable applicator for 60 s and dried with compressed air. After this procedure, the adhesive system Scotchbond Multi-Purpose (3M ESPE, St. Paul, MN, USA) was applied with a disposable applicator and light cured for 20 s. To build the composite resin repair cylinder, plastic colorless tubes (1.1 mm in diameter and 1 mm in height) were used. These were positioned before the hydrophobic adhesive was light activated so that their walls could be aligned with the hole in the adhesive tape. The repair composite was light cured with a bluephase LED (Ivoclar Vivadent, Schaan, Liechtenstein) for 40 s. The original/repair composite resin assemblies were stored at 100% relative humidity for 24 h, after which the plastic tubes and the adhesive tape were removed; the specimens were then stored at 100% relative humidity for 7 days. All repair composite resin cylinders were analyzed with an Olympus BX60 optical microscope (Olympus Corporation, Shinjuku, Tokyo, Japan) at a magnification of 50x to identify any
Table 1: Groups and surface treatments, with detailed descriptions of the mode of application (n=10)

| Groups                              | Surface treatments                          |
|-------------------------------------|---------------------------------------------|
| Negative control                    | No additional treatment                      |
| Al₂O₃ sandblasted: Bioart, São Carlos, São Paulo, Brazil | ALO₃ sandblasting at 50 μm for 10 s, 4 bar of pressure at a 10 mm distance. After this, the specimen was rinsed for 60 s with air/water spray and dried with air for 60 s |
| Alcohol liquid (95% alcohol): Biotec, Labmaster, Pinhais, Paraná, Brazil | Applied actively with a disposable applicator for 2 min, adding more solvent at each 30 s interval. The specimen was subsequently rinsed for 60 s with air/water spray and dried with air for 60 s |
| Alcohol gel (80% alcohol; 5% copolymer of sulfonic acid and vinylpyrrolidone acryloyl dimethyl taurate): Farmadocitor, Curitiba, Paraná, Brazil | No additional treatment                      |

interfacial flaws, gaps, bubbles, or other defects in the original/repair composite resin assemblies. Specimens with defects were replaced. The microshear bond strength test was performed in a universal testing machine (EMIC, São José dos Pinhais, PR, Brazil). The test was performed using a special device attached to the universal testing machine, with a stylet blade positioned closest to the interface and a load cell of 10 kgf at a crosshead speed of 0.5 mm/min until failure occurred.

The determination of the type of failure was performed using digital images obtained with a UC30 Olympus camera (Olympus Corporation, Shinjuku, Tokyo, Japan) attached to an Olympus BX60 optical microscope (Olympus Corporation, Tokyo, Tokyo, Japan) with a magnification of ×50. The areas (pixels) for each type of failure, based on images taken at the same magnification (×50), were measured using the ImageTool program (Department of Dental Diagnostic Science at The University of Texas Health Science Center, San Antonio, Texas, USA). Failures were identified as adhesive (adhesive interface), cohesive in the original composite resin, cohesive in the repair composite resin, or mixed (more than one type).

Ten additional specimens of each composite resin with the repair cylinders were simultaneously constructed with the original composite resin (without separation). This group of specimens was used as the positive control group (cohesive strength of composite resins).

**Atomic force microscopy**

Three additional specimens were prepared for each group and subjected to surface morphological analysis with an atomic force microscope model SPM9500J3 (Shimadzu Corporation, Chiyoda-ku, Tokyo, Japan) using a scanned area of 30/30/10 μm (x/y/z). The images were captured in contact mode using a frequency of 1 Hz and a resolution of 256/256 pixels. SPM Manager Version 2.11 software (Shimadzu Corporation, Chiyoda-ku, Tokyo, Japan) was used in the offline mode to obtain quantitative data on surface roughness (Ra) and for qualitative analysis (three-dimensional [3D] images).

Ten measurements were performed for each group using the three specimens, and a 3D image for each group was selected for the illustration of surface roughness.

**Energy-dispersive X-ray spectroscopy and scanning electron microscopy**

The same specimens evaluated by atomic force microscopy (AFM) were also used for chemical element analysis of the composite resin surfaces after the surface treatments. Two specimens from each group were prepared for energy-dispersive X-ray spectroscopy (EDS). The system was operated at 15 kV and ×30 magnification at a 10 mm distance (detector to sample surface) with a detection region in the center of the specimen (2.5 mm × 3.2 mm, with an 8 mm² area). After the EDS analysis, the same specimens were dried, sputter coated with Au-Pd alloy, and observed under a scanning electron microscope (JSM-6360 LV, JEOL Ltd., Tokyo, Japan). The observation criterion for the images obtained with ×5000 magnification was the presence of modifications on the surfaces of the treated groups compared to the negative control group.

**Statistical analysis**

All treatments were normally distributed according to the Kolmogorov–Smirnov test (P > 0.05). The homogeneity of variance between the three factors was then tested by Levene’s test. When three-way ANOVA suggested differences and the groups showed homogeneity, Tukey’s honest significant difference (HSD) test was used for multiple comparisons. When the variances were not homogeneous, the Games–Howell test was used for multiple comparisons. To analyze the effect of aging on the repair bond strength, the positive control groups for both composite resins (cohesive strength) were excluded to avoid overestimating the repair bond strength values at 7 days. Data analysis of the surface roughness with the Kolmogorov–Smirnov test showed a normal distribution. Levene’s test showed a heterogeneous distribution. When three-way ANOVA suggested the presence of differences,
the Games–Howell test was used for multiple comparisons at a significance level of 5%.

**Results**

The composite resin Filtek Z350 XT had higher cohesive strength (26.97 ± 3.11 MPa) and repair bond strength (15.23 ± 4.85 MPa) than the Empress Direct composite resin (cohesive: 17.27 ± 2.88 MPa; repair: 11.41 ± 3.37 MPa) \( (P < 0.05) \). The aging process analysis, excluding the values of the cohesive groups for both composite resins, showed statistical similarity of the repair bond strength for the nanohybrid composite resin at 7 days (10.71 ± 3.42 MPa) and 6 months (12.12 ± 3.21 MPa), and it showed significant differences for the nanofilled composite resin at 7 days (16.71 ± 4.24 MPa) and 6 months (13.74 ± 5.01 MPa).

The results of the multiple comparisons test (Tukey’s HSD) for the Empress Direct composite resin are shown in Table 2. The acetone liquid and gel groups reached the cohesive strength of the material both times \( (P > 0.05) \). The sandblasted and liquid alcohol groups reached the cohesive strength of the material only after 6 months \( (P > 0.05) \). Only the positive control group differed from the negative control group \( (P > 0.05) \). No significant differences in the repair bond strength were found after the aging process, considering the same surface treatment \( (P > 0.05) \). The percentage of the repair bond strength compared to the cohesive strength of the material ranged from 50.83% (negative control, 7 days) to 79.15% (liquid acetone group, 7 days). During visual examination, the presence of cracks was detected in the specimens of nanohybrid composite resin after water aging (6 months). The images obtained by scanning electron microscopy (SEM) with ×5000 magnification show changes in the composite resin surface after treatment with the solvents [Figures 1 and 2, exposure of the inorganic particles by dissolving the resin matrix] and with sandblasting [Figures 3c, d and 4c, d, damaged surface from the impact of Al₂O₃ particles] compared to the negative control group [Figures 3a, b and 4a, b].

A higher degree of porosity after aging was also noted in the 6-month groups [Figures 1, 2, 3b and d].

The results of the multiple comparisons test (Tukey’s HSD) for Filtek Z350 XT are shown in Table 3. Only the 6-month sandblasted group reached the cohesive strength of the material. The 7-day sandblasted group showed intermediate repair bond strength values, which were significantly different from those of the negative control group. The other treatments were similar to the negative control group at both times \( (P > 0.05) \). The percentage of repair bond strength compared to the cohesive strength of the material ranged between 39.82% (negative control, 6 months) and 83.42% (sandblasted group, 6 months). The SEM images at ×5000 magnification showed few changes in the composite resin surface after solvent treatment [Figures 5 and 6] compared to that of the negative control group [Figure 4a and b], while the

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**Table 2: Means of the bond strength (standard deviation) and the percentages of the repair bond strength of the Empress direct composite resin relative to the cohesive strength according to the surface treatment and the aging process**

| Treatment          | 7 days (MPa) | 6 months (MPa) | 7 days Percentage | 6 months Percentage |
|--------------------|--------------|----------------|-------------------|---------------------|
| Control positive   | 17.27 ± 2.88 | 100            | 100               | 100                 |
| Sandblasted        | 10.55 ± 2.34 | 13.05 ± 3.02   | 61.08             | 75.56               |
| Alcohol liquid     | 9.15 ± 3.80  | 13.55 ± 3.05   | 52.98             | 78.45               |
| Alcohol gel        | 9.73 ± 2.82  | 11.54 ± 2.51   | 56.38             | 66.82               |
| Acetone liquid     | 13.67 ± 2.14 | 12.75 ± 1.95   | 79.15             | 73.82               |
| Acetone gel        | 12.38 ± 3.51 | 12.17 ± 2.90   | 71.68             | 70.46               |
| Control negative   | 8.78 ± 3.32  | 50.83          | 50.83             | 56.10               |

Uppercase letters correspond to statistical similarities in the columns and lowercase to similarities in the rows (Tukey’s HSD). The positive control group can be compared statistically at both periods of the study. HSD= Honest significant difference.
sandblasted groups [Figure 4c and d] exhibited greater surface modification.

The failure type analysis showed a predominance of mixed failures, with a higher percentage area of cohesive failures in the repair composite resin for the sandblasted groups for both composite resins and both times. The groups treated with alcohol and acetone gel for both times and acetone liquid for 7 days showed mixed failures with a larger percentage area of cohesive failures in the repair composite resin only for the nanohybrid composite resin (Empress Direct). Mixed failures with higher percentage areas of adhesive failures predominated in the other groups, with the exception of the acetone liquid, acetone gel, and negative control groups, all at 6 months’ time, for the composite resin Filtek Z350 XT, which failed adhesively.

The Filtek Z350 XT composite resin exhibited a greater average roughness (Ra) than the Empress Direct composite resin. The aging process did not alter the average roughness of the materials. The results of the multiple comparisons test (Games–Howell) are shown in Table 4. For the Empress Direct composite resin, treatments with alcohol increased the surface roughness at 7 days compared to the negative control group. For the Filtek Z350 XT composite resin, acetone liquid and gel and alcohol gel treatments at 7 days and 6 months increased the surface roughness compared to the negative control group \( (P < 0.05) \). The sandblasted groups could not be evaluated by AFM because the surface roughness exceeded the limit of sensitivity of the device. The 3D images for the illustration of the surface roughness for all treatments are presented in Figures 1-6. The results of EDS showed no significant variations in the chemical elements of the surface of the materials after all treatments for both times compared to the negative control group. There was no relevant detection of aluminum chemical elements on the surface of the sandblasted groups.

Table 4: Means of the bond strength (standard deviation) and the percentages of the repair bond strength of the Filtek Z350 XT composite resin relative to the cohesive strength according to the surface treatment and the aging process

| Treatment                  | Z350 XT 7 days (MPa) | Z350 XT 6 months (MPa) | Percentage 7 days | Percentage 6 months |
|----------------------------|----------------------|------------------------|-------------------|---------------------|
| Control positive           | 26.97 (3.11)         | 26.97 (3.11)          | 100               |                      |
| Sandblasted                | 19.50 (4.27)         | 22.50 (3.06)          | 72.30             | 83.42               |
| Alcohol liquid             | 18.08 (3.92)         | 13.28 (3.98)          | 67.03             | 49.23               |
| Alcohol gel                | 17.91 (3.07)         | 12.62 (2.88)          | 66.40             | 46.79               |
| Acetone liquid             | 15.32 (4.00)         | 11.95 (1.89)          | 56.80             | 44.30               |
| Acetone gel                | 16.36 (4.22)         | 11.39 (2.88)          | 60.65             | 42.23               |
| Control negative           | 13.13 (3.47)         | 10.74 (3.53)          | 48.68             | 39.82               |

Uppercase letters correspond to statistical similarities in the columns and lowercase to similarities in the rows (Tukey’s HSD). The positive control group can be compared statistically at both periods of the study. HSD=Honest significant difference.
Discussion

The study hypothesis was rejected because solvents had an effect on the repair bond strength of only one of the composite resins tested. The nanofilled resin exhibited no surface changes after the use of solvents.

Treatment with the organic solvents used in the present study aimed to dilute the polymer.[18] The previous studies have reported that the monomers BIS-GMA, UDMA, and TEGDMA become diluted when they are immersed in acetone and 75% ethanol for storage times of 24 h, 7 days, and 28 days.[13] Both composite resins used in the present study have similar organic compositions, differing only in the presence of PEGDMA and BIS-EMA monomers in the nanofilled composite resin. In this study, neither solvent was able to increase the repair bond strength of the nanofilled composite resin. One possible explanation for this result could be the type, size, quantity, and distribution of inorganic particles in the material, which produce a smaller portion of organic matrix area for the action of solvents. The greater amount of small filler particles associated with clusters promotes a decrease in the interstitial space between the inorganic particles that protect the polymeric matrix.[19,20] The images obtained by SEM showed that the solvents did not induce relevant changes in the surface of the nanofilled composite resin.

In contrast, the solvents had a more significant effect on the nanohybrid composite resin because their use results in repair bond strengths similar to the cohesive strength of the material for liquid alcohol at 6 months and for acetone liquid and gel at both time periods. This fact may be related to the inorganic and organic composition of the material.[19,20] The SEM images showed that the application of solvent promoted the removal of the organic matrix on the surface of the material, exposing the inorganic particles. Based on these results, it can be stated that the Empress Direct composite resin presents a greater amount of matrix on the surface and a greater susceptibility to solvent action due to the size and distribution of the filler particles in the organic matrix.

In addition to the dilution of the surface polymer matrix of the original composite resin, the use of solvents can also facilitate the access of repair composite resin to

Table 4: Average roughness (nm) and standard deviations according to the types of surface treatment, composite resin, and water-aging procedure

| Treatment           | Empress direct 7 days | Empress direct 6 months | Z350 XT 7 days | Z350 XT 6 months |
|---------------------|-----------------------|-------------------------|----------------|-----------------|
| Alcohol liquid      | 52.50 (5.19)          | 48.72 (10.76)           | 62.32 (11.88)  | 59.01 (10.89)   |
| Alcohol gel         | 60.28 (9.11)          | 49.26 (5.72)            | 98.46 (11.19)  | 83.83 (20.30)   |
| Acetone liquid      | 47.81 (3.42)          | 49.26 (5.72)            | 77.03 (15.92)  | 97.68 (12.65)   |
| Acetone gel         | 42.16 (3.78)          | 52.42 (12.17)           | 103.75 (23.03) | 69.21 (14.67)   |
| Control negative    | 41.25 (5.19)          | 48.72 (10.76)           | 59.01 (10.89)  | 67.13 (10.50)   |

Uppercase letters correspond to statistical similarities in the columns and lowercase to similarities in the rows (Game–Howell)
values should range between 15 and 25 MPa. A previous study that used shear bond strength to evaluate resins.

Composition similar to that of microhybrid composite a combination of nano- and micro-sized fillers with an inorganic filler. Better distribution between the organic matrix and the particles bonded to form larger “clusters,” permitting a better distribution between the organic matrix and the inorganic filler. Nanohybrid composite resins have a combination of nano- and micro-sized fillers with a composition similar to that of microhybrid composite resins.

A previous study that used shear bond strength to evaluate composite resin repair recommended that effective values should range between 15 and 25 MPa. The values found in the current study are consistent with that recommendation. The nanofilled composite resin showed repair bond strength above the minimum in the sandblasted group at both times and in the solvent-treated groups after 7 days. The nanohybrid composite resin exhibited repair bond strength values below the minimum suggested by the aforementioned study.

The aging process used in this study consisted of 6 months of immersion in water at 37°C. The hydrolytic degradation of the composite can occur either in the polymer matrix or in the silanization area of the filler particles. Such a process can affect the physical and mechanical properties of the composites, thus also affecting the repair bond strength of the material surface. In the present study, the repair bond strength values of the nanofilled composite resin decreased after the aging process whereas the repair bond strength values of the nanohybrid composite resin did not change significantly. The previous studies have reported that nanofilled composite resins are more susceptible to sorption than hybrid composite resins. This susceptibility could be attributed to the fact that this material presents a greater surface area of inorganic particles (agglomerated and nonagglomerated) and contains a greater amount of silane, which is prone to hydrolytic degradation. Another feature that possibly contributes to the further deterioration of the nanofilled composite resins is the diffusion of water through the agglomerated silica/zirconia, which may occur due to poor polymer impregnation within these clusters.

In composite repair studies, it is necessary to obtain the comparison values of the cohesive strengths of the materials. It is then possible to compare the repair bond strengths of the suggested surface treatments with the cohesive strength of the material. In this study, the repair bond strengths varied from 39.82% to 83.42% of the cohesive strength of the materials, which is compatible with the results of the previous studies. In 6 months, the sandblasting treatment resulted in 83.42% of the cohesive strength for Filtek Z350 XT and 75.56% for Empress Direct. Both groups were statistically similar to their respective positive control groups (cohesive strength). The micromechanical retention created by Al₂O₃ sandblasting is important to ensure adhesion between the aged composite resins and the new repair composite resins. The previous studies have reported that Al₂O₃ sandblasting can induce microretention on the composite surface, promoting a larger area for wetting, and bonding to the adhesive system. The images obtained by SEM showed the surface appearance of the composite resins after Al₂O₃ sandblasting, in which a large area of microretention is observed, even after the aging process. The results of this study corroborate those of other studies and show, with data obtained by EDS analysis, the absence of aluminum on the surface of sandblasted composite resins. It is likely that washing with a triple syringe removed the aluminum from the surface of the material. In addition, it is important to

Figure 6: Scanning electron microscopy and three-dimensional atomic force microscopy images of the Filtek Z350 XT composite resin: (a) Alcohol gel group at 7 days; (b) alcohol gel group at 6 months; (c) alcohol liquid group at 7 days; (d) alcohol liquid group at 6 months. Filler particles were not exposed, indicating minimal effect of the solvent independent of the aging process.

unpolymerized C = C groups. In repairs that take place at 7 days, this polymerization process may be more likely to occur. However, in the aged composite resin, this process cannot occur, or it occurs to a lesser degree because of the leaching of unreacted monomers and the hydrolytic degradation of the material when exposed to water, which decreases the amount of unreacted monomers in the aged material.

The inorganic particles used in the composite resins significantly interfere with properties such as flexural strength, elastic modulus, and wear resistance. Due to these factors, the composite resins are classified according to the characteristics of their inorganic particles such as the type, size distribution, and mean particle size. In the present study, the highest values of cohesive strength were obtained with the nanofilled composite resin, as well as the repair bond strength, which agrees with the results of other studies investigating this material. These results may be related to the characteristics of the fillers of this material which provide a favorable mechanical behavior. The nanofilled composite resins are characterized by an inorganic portion composed only of nanoscale particles and agglomerates, also composed by nanometric particles bonded to form larger “clusters,” permitting a better distribution between the organic matrix and the inorganic filler. Nanohybrid composite resins have a combination of nano- and micro-sized fillers with a composition similar to that of microhybrid composite resins.

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emphasize that the roughness obtained in the sandblasted groups was so high that it could not be analyzed by AFM. The application of an adhesive layer after the surface treatment of the composite resin has been described in the literature as being critical to the repair procedure. The adhesive system promotes greater wettability of the composite resin surface, and because of its low viscosity, it penetrates and polymerizes in the microtretentions on the surface, improving the repair bond strength.[9,10] The use of a silane coupling agent for composite resin repair depends on the inorganic composition of the composite resin to be repaired. When the inorganic phase of the composite resin presents silica-based components, the silane can facilitate a better repair bond strength because of the chemical bonding between the inorganic particles and the applied adhesive system.[6,8,9,11] In this study, both the adhesive system and silane coupling agent were included in the repair procedure, as there is scientific confirmation of the contribution of these two factors to the repair bond strength of composite resins.

The analysis of the types of failure showed a higher occurrence of cohesive failures in groups with higher repair bond strengths, which corroborates the results of the previous studies.[5,18,28,31] Analysis of the surface roughness of the materials showed that solvents modified the surfaces of both materials. However, no other treatment was as effective in creating microretentions as Al₂O₃ sandblasting. The average roughness after all solvent treatments indicated that the treated surfaces resembled polished surfaces.[42] More studies are needed to better understand the overall effect of organic solvents on the repair of different composite resin types available. It must also be taken into consideration that the dentist is not always aware of the type of composite material on which the repair will be made. Thus, it becomes advantageous for a repair procedure to be effective regardless of the type of composite resin.

**Conclusion**

Within the limitations of this in vitro study, the following conclusions can be drawn:

- The nanofilled composite resin showed greater repair bond strength and cohesive strength than the nanohybrid composite resin.
- Al₂O₃ sandblasting was more efficient in augmenting the repair bond strength of the nanofilled composite resin, and it promoted greater surface roughness for both composite resins.
- The organic solvents were more efficient in establishing a favorable repair bond strength for the nanohybrid composite resin than for the nanofilled composite resin.
- The aging process was more detrimental to the repair bond strength of the nanofilled composite resin than to that of the nanohybrid composite resin.
- The use of solvents was material dependent whereas the use of Al₂O₃ sandblasting exhibited favorable results for both tested materials.

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**Conflicts of interest**

There are no conflicts of interest.

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