INTRODUCTION

In daily clinical practice, failure of composite restorations is an important concern. Failed restorations are commonly replaced; however, replacement procedures can lead to excessive removal of sound tooth, weaken the tooth structure, and sometimes lead to pulp exposure. To avoid these complications, it is preferable to repair the restorations instead of replacing them. Repair is a minimally invasive method that helps in preserving the tooth structure and enhancing the longevity of the restoration. Repair of resin composite restorations is generally preferred over total replacement, as it is more cost-effective and significantly improves the longevity of both the tooth and the restoration.

For successful dental composite repairs, achieving strong adhesion to the existing restoration is an important factor. Bonding to aged composite resin restorations is highly challenging, mainly due to the diminished number of available C=C bonds to react with the new material. Considering this, surface treatment of the aged restoration serving as the bonding substrate is performed to improve the repair bond strength of composite resins. For this purpose, various surface conditioning methods have been developed based on physical, physico-chemical, or chemical adhesion principles; however, there is no consensus as to which treatment increases the success of repair.

Recently, the use of bulk-fill resin composites has been increasing among practitioners due to the ease of their application. Different from incremental techniques recommended for conventional composite resins, bulk-fill composites are claimed to be useful in bulk placement of up to 4 mm thick layers. Due to their advantages in application technique, bulk-fill resins have been increasing in popularity among dental practitioners, and as it occurs with conventional resin-based composites, bulk-fill materials are also susceptible to fracture and discoloration. As a result, dentists could consider repairing these restorations; however, bulk-fill composite formulation includes different monomers and various additives, some of which are unknown, that could diminish their potential repair. To the best of our knowledge, there is little evidence in the literature about which procedures could be best used to repair these restorations.

Thus, the purpose of this study was to evaluate the effect of different adhesive protocols on the shear bond strength (SBS) of bulk-fill resin composite repaired with bulk-fill or conventional composite. Cylindrical bulk-fill resin composite specimens were prepared and allocated into groups according to the bonding strategy: no treatment, Silane+Scotch Bond Multipurpose (S+SBMP), Tetric N Bond Universal, and Single Bond Universal. Following bonding strategy, bulk-fill or conventional composite buildups were performed. After 24 h of storage in distilled water at 37°C, shear force was applied to the interface using a universal testing machine. The data were analyzed by two-way ANOVA and Tukey test (α=0.05). SBS was influenced by the bonding strategy and the composite used (p<0.001). Irrespective of the composite used, the group S+SBMP yielded the highest SBS values (p<0.001). Repair bond strength of bulk-fill composites can be improved by using a silane coupling agent followed by a hydrophobic resin.

MATERIALS AND METHODS

The composition and manufacturer details for the materials employed in this study are listed in Table 1. Sixty cylindrical specimens (1.0 mm in thickness, 6.0 mm diameter) were prepared using Filtek™ Bulk Fill resin composite (Shade A2, 3M ESPE, St Paul, MN, USA). Specimens were prepared filling the uncured material.
Table 1  Composition of materials used

| Materials                          | Batch No. (Manufacturer)                           | Main Components*                          |
|-----------------------------------|--------------------------------------------------|-------------------------------------------|
| AdperTM ScotchbondTM Multi-Purpose Adhesive | N763504 (3M ESPE, St Paul, MN, USA)                | BisGMA; HEMA; triphenylantimony           |
| Single Bond® Universal            | 645031 (3M ESPE)                                 | HEMA; Bis-GMA; DDMA; ethanol; Silane treated silica; water; 2-propenoic acid; 2-Methyl-; reaction products with 1,10-decanediol and phosphorous oxide; copolymer of acrylic and itaconic acid; DMAEMA; CQ; EDAB; 2,6-di-tert-butyl-P-cresol |
| Tetric® N-Bond Universal          | V25219 (Ivoclar-Vivadent, Schaan, Liechtenstein) | HEMA; Bis-GMA; ethanol; DDMA; Methacrylated phosphoric acid ester; CQ; DMAEMA |
| Prosil®                           | 170717 (FGM, Joinville, SC, Brazil)              | Etanol; MPS; water                        |
| Filtek™ Z350 XT                   | 688004 (3M ESPE)                                 | Silane Treated Ceramic; Silane Treated Silica; Silane Treated Zirconia; UDMA; BisEMA; BISGMA; PEGDMA; TEGDMA |
| Filtek™ Bulk Fill                 | N867072 (3M ESPE)                                | Silane Treated Ceramic; Ytterbium Fluoride; Silane Treated Silica; Silane Treated Zirconia; DDDMA; UDMA; Aromatic Urethane Dimethacrylate; Water; Pentanedioic acid, 2,2-dimethyl-4-methylene-, reaction products with glycidyl methacrylate; Ethyl EDMAB; Benzotriazol; Titanium Dioxide |

Bis-GMA: bisphenol-A-diglycidyl methacrylate; Bis-EMA: bisphenol-A-polyethylene glycol diether dimethacrylate; PEGDMA: polyethylene glycol dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; HEMA: 2-hydroxyethyl methacrylate; UDMA: urethane dimethacrylate; DDMA: decamethylene dimethacrylate; DDDMA: 1,12-dodecanediyl dimethacrylate; DMAEMA: dimethylaminomethyl methacrylate; CQ: camphorquinone; EDAB: dimethylaminobenzoate; MPS: 3-methacryloxypropyltrimetoxisilane.  *Information as provided by manufacturers.

![Experimental design](image)

Fig. 1  Experimental design.

into a silicon mold placed on a glass slide covered by a Mylar® strip. A second strip and a glass slide were used to cover the mold. The samples were irradiated on both sides for 20 s using a photopolymerization unit (Radii, SDI, Bayswater, Australia) with an intensity of 900 mW/mm². After removal from the silicon mold, the specimens were divided into five experimental groups (n=12), as shown in Fig. 1.

Specimens allocated into the control group were immediately restored without further surface treatment protocol (see above). The remaining specimens were subjected to an aging procedure by thermo-cycling (10,000
cycles at 5–55°C, dwell time of 30 s). After thermocycling, specimens were embedded in polyvinyl chloride tubes using cold-cure poly (methyl) methacrylate and the surfaces of all specimens were wet-polished with 600-grit silicon carbide paper under water cooling for 30 s. They were then divided into five groups (n=12) according to different surface treatment protocols as follows:

Control group: No aging and no treatment applied to the surface. Aged control group: No treatment applied to the surface. Group S+SBMP: Using a disposable applicator, silane coupling agent (Prosil®, FGM, Joinville, SC, Brazil) was vigorously wiped on the surface for 20 s. The silane was left undisturbed during 1 min and then dried with a gentle stream of air. Afterwards, a coat of Adper™Scotchbond™Multi-Purpose (3M ESPE) adhesive was applied and light-cured for 10 s. Group TBU: Tetric® N-Bond Universal (Ivoclar-Vivadent, Schaan, Liechtenstein) adhesive was scrubbed into the disk surface for 20 s. The adhesive was then dispersed until a glossy, immobile film layer resulted. The adhesive was then light-cured for 10 s. Group SBU: Single Bond® Universal (3M ESPE) was applied to the entire disk surface and rubbed for 20 s. Subsequently, a gentle stream of air was applied over the liquid for 5 s followed by light-curing for 10 s.

Following the surface treatments, elastomer molds with two cylindrical orifices (1.5 mm in diameter and 0.5 mm in thickness) were placed on the surface resin discs. Each orifice was filled with a different composite material: one with Filtek™ Bulk Fill and the other with Filtek™ Z350 XT (Shade A2, 3M ESPE); the molds were then covered with a polyester strip and a glass slide and the resin composites were photo-activated for 20 s each.

After storage in distilled water at 37°C for 24 h, a stainless steel wire (0.2 mm in diameter) was looped around each cylinder and aligned with the bonded interface. The SBS test was conducted on a mechanical testing machine (DL500, EMIC, São José dos Pinhais, PR, Brazil) at a crosshead speed of 0.5 mm/min until failure. Failures were observed under a magnification of up to 40× using a stereomicroscope to determine the failure mode as follow; adhesive (interfacial) or cohesive resin. Representative specimens of each failure type were selected and evaluated by scanning electron microscopy (Fig. 2).

The statistical tests were done using Sigma Plot 12.0 software. The data were analyzed to verify the normal distribution and variance homogeneity. A two-way ANOVA test was performed to analyze the effect of the composite resin surface treatment and the composite material used for the repair on the SBS. Multiple comparison procedures were performed using the Tukey test. The Student’s t-test was applied to compare the SBS values using different composites for each surface treatment. For all tests, the level of significance was set to p<0.05.

RESULTS

The means and standard deviations of the SBS values for each experimental group are summarized in Fig. 3. The 2-way ANOVA reveals that SBS values were significantly influenced by both factors; the surface treatment (p<0.001) and the composite used for the repair procedures (p<0.001); however, the interaction between these factors was not significant (p=0.080).
Fig. 3  Shear bond strength as a function of repair material and surface treatment. Columns under the same horizontal line indicate no differences between repair materials for each surface treatment. Uppercase letters indicate differences between surface treatments when Filtek™ Bulk-fill was used as repair material. Lowercase letters indicate differences between surface treatments when Filtek™ Z350 XT was used as repair material.

Fig. 4  Failure mode distribution in percentage (%) for treated composite resin specimens using Filtek™ Bulk-fill or Filtek™ Z350 XT as repair material.

The Student’s t-test did not show significant differences in the SBS means after repair procedures using Filtek™ Bulk-fill or Filtek™ Z350 XT, except for the group treated with silane coupling agent and hydrophobic resin, SBMP (p=0.002). Comparatively, the treatment using Silane+SBMP showed significantly higher SBS when applied in Filtek™ Bulk-Fill group than applied in Filtek™ Z350 XT group. In addition, this protocol showed to be the better between the five different protocols tested in this study for both resins evaluated Filtek™ Bulk-fill and Filtek™ Z350 XT.

The failure mode distribution for the different surface treatments and composites used for the repair procedures are shown in Fig. 4. For the specimens without surface treatments, all failures are adhesive for both composite repair materials. When silane coupling agent was followed by a layer of hydrophobic resin as surface treatment, failures are predominantly cohesive; this behavior also occurred when Single Bond Universal and Tetric Bond Universal were applied as surface treatment.

DISCUSSION

For successful dental composite repairs, achieving strong adhesion to the existing restoration is an important factor9). Thus, it is meaningful to compare the effect of different surface treatments on the SBS of aged bulk-fill resin composite repaired with bulk-fill composite or with conventional nanoparticle composite. In this study, the null hypotheses tested were partially rejected. Our results showed that the different surface treatment techniques influenced the bond strength of the repair. However, there was no difference in bond strength between the composite resins used for repair, except for the specimens treated with silane coupling agent and hydrophobic resin.

Composite repair often presents a different challenge, especially because the surface of aged composites lacks any unreacted double bonds available for bonding to the new composite10,11). Although there is no laboratorial aging protocol considered as gold standard that simulates this phenomenon, some authors have followed the principle that 10,000 cycles correspond to one year of physiological aging in the oral cavity8), what would be enough to promote a considerable increase in the double bond conversion of composite materials. As expected, based on this fact, the lowest values of SBS were obtained for the aged groups, where no surface treatment was employed before the repair process. Analysis of failure patterns demonstrated that the predominant failure type for these groups was the adhesive type, which demonstrates that there was no physical or chemical interaction between the new and the aged composite. This was confirmed by SEM analysis, where representative images of the adhesive failure type confirmed that the surfaces were scarcely altered by the repair procedure. These results emphasize the importance of treating aged composite surfaces by chemical or physical processes before any attempted repair procedure.

With regard to composite repair, there is no consensus about which protocol or materials should be used for treating aged composite surfaces. In this study,
it was demonstrated that, independent of the type of composite used, the application of a silane coupling agent combined with a layer of bonding agent leads to a better adhesion of the resin composite used for the repair process. The results obtained are in accordance with those obtained in a recent systematic review with meta-analysis\textsuperscript{18}. In an aged resin composite, it could be hypothesized that some filler particles are exposed, and therefore the use of a silane coupling agent is justified because this agent is able to form covalent bonds with such particles, and is also able to co-polymerize with the methacrylate groups of the repair material\textsuperscript{19}. Also, silane enhances the wettability of the surface, making it more amenable to diffusion of the bonding agent into the substrate\textsuperscript{10}. The analysis of failure from specimens from this group showed that the most frequent type of failure was cohesive, which helps to demonstrate that the adhesive forces achieved with this repair protocol are higher than the cohesive strength of the resin composite material.

In this study, two universal adhesive systems were tested as chemical surface treatments before the repair procedures. This new type of adhesives is indicated for adhesion on different substrates, including composite resins, dental ceramics, and alloys\textsuperscript{15}. The universal adhesive systems used were Tetric N Bond Universal and Single Bond Universal which, according to the manufacturers, are indicated for the repair of fractured composite restorations. The main difference between these adhesives is that Single Bond Universal contains an organosilane agent in its composition, potentially eliminating the silanization step when bonding to glass ceramics or resin composites\textsuperscript{16}. As can be seen in Fig. 3, there was no statistically significant difference between the SBS achieved with the two universal adhesives employed. Based on these results, it can be seen that the performance of the universal adhesives for the adhesion in composite resins is independent of the presence of the silane in their composition. On the other hand, the absence of any positive effect by silane contained in the universal adhesive could be explained due to its low stability in the water acidic adhesive solution, where the silanol groups formed by hydrolysis may undergo dehydroxylation and condensation to form an oligomer that can no bond to glass\textsuperscript{17}.

It has been suggested that the type of resin is the main factor influencing the bond strength of the repair\textsuperscript{18}, and some studies have recommended that the repair process be executed with the same composite resin used to perform the original restoration\textsuperscript{19}. The results from this study suggest that bulk-fill composite can be repaired with either bulk-fill or conventional composite. Moreover, that the pretreatment of the substrate with silane coupling agent and adhesive system leads to higher SBS. In addition, it seems that using the same bulk-fill composite in the repairing process could improve the effectiveness of the procedure, which can be explained by the presence of similar monomers within their composition, which allow an adequate copolymerization between the methacrylate groups of the new and aged composite\textsuperscript{20}. Considering this, it is worth mentioning that, when performing a composite restoration, it is extremely important to document correctly the type of material used, so that the operator can ensure adequate bond strength of the repair when necessary.

CONCLUSIONS

With the limitations due to a long distance between laboratory studies and clinical randomized evaluations, this study implies that pretreatment with silane coupling agent and the application of a hydrophobic resin can improve bond strength of bulk-fill repaired restorations, and when this system is used, it is better to use the same bulk-fill composite.

ACKNOWLEDGMENTS

Author Carlos Enrique Cuevas-Suárez wants to thanks to PRODEP, México for scholarship (DSA/103.5/15/6615).

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