

# Flexural Strength of Conventional or Bulk-fill Resin Composite Repaired with High- or Low-viscosity Restorative Materials

AV Foscarini • LS Barros • CP Turssi • FMG França • RT Basting • WF Vieira Junior

## Clinical relevance

The tested bulk-fill resin can be repaired using conventional resin composite without decreasing flexural strength. Low-viscosity materials used for repairs presented higher flexural strength compared to their high-viscosity counterparts and may be a better choice to repair restorations.

## SUMMARY

**Objective:** To evaluate the flexural strength of two types of high-viscosity resin composites (conventional or bulk-fill) that were repaired with either high-viscosity composites (conventional or bulk-fill) or low-viscosity composites (conventional or bulk-fill) of the same manufacturer (3M Oral Care, St Paul, MN, USA).

### Methods and Materials: Specimens (25 mm x

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2 mm x 2 mm) of both conventional nanofilled resin (Filtek Z350XT), and bulk-fill nanofilled resin (Filtek One Bulk Fill) were prepared. After fracture of the specimens in the 3-point bending test (initial), half of the specimens were repaired immediately afterwards (24 hours), and the other half were repaired after 6 months of storage in distilled water. Repairs were performed with (n=15) high-viscosity resin composites (Filtek Z350XT, Filtek One Bulk Fill), or their low-viscosity versions (Filtek Supreme XT Flow, Filtek Bulk Fill Flowable Restorative). The repair was

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performed by roughening the surface and applying phosphoric acid, silane, and adhesive. The bending test (results reported in MPa) was performed in a universal testing machine, and the fracture pattern was determined. Data were evaluated by generalized linear models, chi-square test and the Fisher exact test ( $\alpha=0.05$ ). Results: There was no significant difference between the former pair of high-viscosity resins in terms of initial flexural strength ( $p=0.42$ ). The repairs performed with low-viscosity resin composites after 24 hours or 6 months obtained higher MPa values compared with those using high-viscosity composites ( $p=0.0006$ ). There was a significant decrease in MPa values when the repair was performed after 24 hours and an increase after 6 months, regardless of the material ( $p<0.0001$ ). After 6 months, fractures involving the old (conventional) resin were more frequent in the repair performed with bulk-fill resin composites compared with the conventional composites ( $p=0.02$ ).

**Conclusions:** Considering the tested products, the material to be repaired did not influence the flexural strength of the repair composite; however, the use of the low-viscosity resin composites resulted in greater flexural strength of the repaired material. The repair of the aged composite resulted in an increase in its flexural strength, regardless of the material repaired or used to perform the repair.

## INTRODUCTION

Repair is a minimal intervention method that helps preserve tooth structure and increases the longevity of the restoration.<sup>1</sup> Proper repair or replacement of failed restorations is crucial because the likelihood of loss of dental tissue increases with each intervention, and the treated tooth is further weakened.<sup>2</sup> Repair has advantages over total replacement of the restoration, including greater preservation of tooth structure, lower risk of pulp damage, reduced need for local anesthesia, and shorter treatment time.<sup>2,3</sup>

The great challenge in repairing resin composites is the difficulty of adhesion of a new resin to the aged resin since the aged resin will have undergone changes after its insertion in the mouth, such as water absorption, chemical degradation, and loss of inorganic particles.<sup>4</sup> Bonding to aged composite restorations can be challenging,<sup>1,3</sup> and although bonding options have been widely researched, the impact of the repair procedure on other physical-mechanical properties of restorative materials is rarely investigated.

Resin composite restorations are routinely performed in clinical dental practice because of the favorable properties of resin materials, especially in esthetics, and also because of the ongoing evolution of adhesive systems that allow treatments with minimal intervention.<sup>5,6</sup> Despite the many advantages of a resin composite, its placement is technique sensitive, and poses a challenge to many professionals. Bulk-fill resin composites were developed to facilitate the restorative technique.<sup>7</sup> Studies suggest that these composites have a greater depth of cure, allowing insertion in layers up to 4-5 mm thick.<sup>8,9</sup>

Based on the different strategies, bulk-fill resin composites can be categorized into two forms according to their viscosity.<sup>9</sup> Fluid (flow) or base bulk-fill composites seem more suitable for narrow cavities that are deeper than 4 mm or less accessible, particularly because their lower viscosity offers a better potential for adaptability.<sup>10</sup> In larger cavities, regular bulk-fill composites (paste) with high-filler loading are preferable.<sup>9</sup> Bulk-fill resin composites belong to a new category of resins with different compositions, but, similar to conventional resin composites, they are also susceptible to degradation.<sup>1,11</sup>

Professionals may consider repairing bulk-fill restorations; however, the bulk-fill resin composite formulation includes various different monomers and several additives, some of which are unknown or protected by patents, hence challenging the repair potential of these materials.<sup>1</sup> There is no consensus in the literature on what procedures are best indicated to repair these restorations, especially as regards the impact of the properties of the material to be used in the repair. For this reason, flexural strength tests are indicated to measure the mechanical behavior of materials subjected to different types of stresses.<sup>12</sup> Further studies on bulk-fill repair are important to assess whether the inherent differences in this material versus conventional composites affect the final strength of the repairs.<sup>7</sup>

Therefore, the objective of this study was to evaluate the flexural strength of high-viscosity resin composites (conventional or bulk-fill) that were repaired with either high-viscosity composites (conventional or bulk-fill) or low-viscosity composites (conventional or bulk-fill) of the same manufacturer (3M). The initial null hypotheses were: 1) there is no difference in the flexural strength of bulk-fill resin composites compared with conventional resin composites of the same manufacturer (3M); 2) there is no difference in the flexural strength of the different materials used in performing the repair if products of the same manufacturer (3M) are used.

## METHODS AND MATERIALS

### Experimental Design

This laboratory study used 120 bars made of resin composite ( $n=15$ ), sixty with conventional nanofilled resin composite (Filtek Z350XT, 3M Oral Care, St Paul, MN, USA), and sixty with bulk-fill nanofilled resin composite (Filtek One Bulk Fill, 3M Oral Care). Flexural strength tests were performed at three time points: initial (baseline), when the repair was made 24 hours later, and when it was made 6 months later. The materials used for the repair were the following:

1. Conventional nanofilled resin composite (Filtek Z350XT, 3M Oral Care);
2. Conventional flow nanofilled resin composite (Filtek Supreme XT Flow, 3M Oral Care);
3. Bulk-fill nanofilled resin composite (Filtek One Bulk Fill, 3M Oral Care);
4. Bulk-fill flow nanofilled resin composite (Filtek Bulk Fill Flowable Restorative, 3M Oral Care).

Response variables were the three-point bending test (flexural strength, MPa) and the fracture pattern (%). The sample size calculation was performed in G\*Power 3.1.5 software (Heinrich Heine Universität, Düsseldorf, Germany), considering the following parameters:  $\alpha = 0.05$ ,  $1-\beta = 0.8$  (power), effect size = 0.3918, and mean standard deviation, which were calculated from a pilot study ( $n=3$ ). Considering the difference between the repair materials, the calculation indicated  $n = 13$ ; thus, the study was conducted with  $n = 15$  specimens per group.

### Preparation of the Specimens

Sixty specimens of conventional nanofilled resin composite, and sixty specimens of bulk-fill nanofilled resin composite were made in the shape of a bar measuring 25 mm long, 2 mm thick and 2 mm wide.<sup>13</sup> The procedure consisted of inserting the resin composite into a silicone mold<sup>14</sup> (Express XT, 3M Oral Care), using a spatula (Maximus Erpo 2, Maximus ICIHO, Contagem, MG, Brazil). The malleability of the silicone mold allowed removal of the specimens without inducing stress, and a controlled location for making the future repair. The resin composite was then covered with a polyester strip and a glass slide on which an axial load of 1 kg was applied for 30 seconds. The mold featured a secure margin of elastomeric material to withstand the pressure without deforming the specimens. Next, the glass slide was removed, keeping the polyester strip in contact with the resin to protect it from the oxygen-inhibiting layer. Soon afterwards, the material was light-cured on the upper surface of the

specimen, using a light-emitting diode (LED) (Valo, Ultradent, South Jordan, UT, USA) in standard power mode (1000 mW/cm<sup>2</sup>) for 20 seconds at three points along the bar. The bars were then removed carefully from the mold, and the unexposed surface was exposed to additional light curing at all three points. Any excesses were removed with a #15 carbon scalpel blade (Solidor, Santa Catarina, Brazil).

The specimens were stored in a lab oven in distilled water at 37°C for 24 hours. After preparation, the specimens were randomized into study groups. A digital caliper (Mitutoyo, Kawasaki, Kanagawa, Japan) was used to measure the specimens; then the initial flexural strength test was performed.

### Flexural Strength Test

The bending test was performed with an apparatus consisting of a base fixed to the universal testing machine (Emic, São José dos Pinhais, PR, Brazil), equipped with a load cell of 50 kgf. The test was carried out on the specimens at the initial, 24-hour, and 6-month time periods. The specimens were made, and the first flexural strength test was performed after 24 hours. The repair was made on one half of the specimens after another 24 hours, then underwent flexural strength testing after an additional 24 hours. After 6 months, the other half of the first test specimens was repaired and after 24 hours underwent flexural strength testing.

The device for assessing flexural strength consisted of two rods with a 2-mm-diameter, parallel to each other, and at a distance of 10 mm between their centers. A tip with a 2-mm-diameter circular section was attached to the clamp of the testing machine. The tip applied a compressive load to the specimen positioned in the device, at a speed of 0.75 mm/min. The flexural strength (MPa) was calculated according to the following formula:

$$\sigma = \frac{3Fl}{2bh^2},$$

where " $F$ " is the maximum load (N), " $l$ " is the distance between the two support points (mm), " $b$ " is the width (mm), and " $h$ " is the height of the specimen (mm).

### Making the Repairs

The specimens that broke in the 3-point bending test were repaired at both 24 hours and 6 months as follows: first the surface of each specimen was mechanically treated with a #4138 diamond point (KG Sorensen, Cotia, SP, Brazil) kept in contact for 5 seconds at high speed under air/water cooling in order to plane and roughen<sup>15</sup> the surface to be repaired. The diamond

point was replaced after every five specimens. Following this procedure, the surfaces were exposed<sup>7</sup> to 35% phosphoric acid (Ultra-Etch, Ultradent, Indaiatuba, SP, Brazil) for 30 seconds, and the specimens were rinsed with air/water aerosol for 30 seconds and dried for 10 seconds. Silane (RelyX Ceramic Primer, 3M Oral Care) was applied to the surface of the specimens for 1 minute,<sup>16,17</sup> after which the specimens were air-dried for 10 seconds to evaporate the solvent. A drop of universal adhesive (Single Bond Universal, 3M Oral Care) was applied to the entire surface and was rubbed actively for 20 seconds, after which the specimen was subjected to a light air blast for 5 seconds, and light-cured for 10 seconds.

The repair procedure was performed by placing the fractured specimens in the silicone matrix after they received the surface treatments and repairing them using the new materials. A polyester strip, glass slide, and 1 kg of weight were placed on the surface for 30 seconds. The weight and slide were removed, and the material was light-cured on the upper surface of the specimen using a light-emitting diode (LED) (Valo, Ultradent) in standard power mode (1000 mW/cm<sup>2</sup>) for 20 seconds at two points along the bar, at the adhesive interface, and at the extremity of the new resin composite, using visible LED light. The bars were then removed carefully from the matrix, and the unexposed surface was exposed to additional light-curing at the two points. Any excesses were removed with a #15 carbon scalpel blade (Solidor).

The materials used to perform the repairs were (n=15) conventional nanofilled resin composite (Filtek Z350XT, 3M Oral Care), conventional flow nanofilled resin composite (Filtek Supreme XT Flow, 3M Oral Care), bulk-fill nanofilled resin composite (Filtek One Bulk Fill, 3M Oral Care), and bulk-fill flow nanofilled resin composite (Filtek Bulk Fill Flowable Restorative, 3M Oral Care). The information on the materials used in this study is given in Table 1.

After 24-hour storage in distilled water at 37°C, the repaired specimens were measured in height and width with a digital caliper (Mitutoyo) and subjected to the three-point bending test as described above. After fracture, the fracture pattern was analyzed under a stereoscopic microscope (EK3ST, Eikonol, São Paulo, Brazil) at 40× magnification by a blinded evaluator who did not participate in the specimen preparation. The same procedure was performed after 6 months of storage in distilled water at 37°C. As shown in Figure 1, the fracture patterns were classified as failure occurring in old resin, interface/old resin, interface, new resin, interface/new resin, and a mixed combination (old resin, new resin, and interface).

### Statistical Analysis

Descriptive and exploratory analyses of the data were performed initially. The flexural strength data were analyzed by mixed generalized linear models; evaluations of the model were performed on the same specimens at the initial time point (before repair), and when repaired after 24 hours and after 6 months. Chi-square and Fisher exact tests were used to analyze the fracture pattern. The analyses were performed using the R program (R Foundation for Statistical Computing, Vienna, Austria), with a significance level of 5%.

### RESULTS

The flexural strength (MPa) results are shown in Table 2. The triple interaction ( $p=0.5174$ ), and the interaction between the factors of repaired resin composite and repair material ( $p=0.5791$ ) were not statistically significant; however, statistically significant interactions (Table 3) were found between the factors of repaired resin composite versus time ( $p=0.036$ ), and repair material versus time ( $p=0.0419$ ).

As shown in Table 3, comparing the different time periods, the repair performed in the conventional and bulk-fill resin composites after 24 hours was found to have a significant decrease in the flexural strength of both resin composites at the initial time point, regardless of the material used to make the repair. However, when the repair was performed at 6 months, the strength was significantly higher for both resin composites, compared with the initial pre-repair time and the 24-hour repair time. Considering the initial values, no significant differences were observed between the conventional and bulk-fill resin composites in terms of flexural strength ( $p=0.4278$ ). After the repair, the flexural strength was significantly higher in the low-viscosity repair materials (LVC and LVB) than in the high-viscosity repair materials (HVC and HVB), regardless of the repaired resin composite, both at the 24-hour and 6-month repair periods. There was no significant difference between the two low-viscosity materials.

Table 4 presents the frequency distribution of the fracture patterns according to the repair material and the time point. No significant association was found between the repair material and the fracture pattern in the conventional resin group at the 24-hour repair time ( $p=0.0997$ ). As for the bulk-fill resin composite, there was also no significant association between repair material and fracture pattern after 24 hours or after 6 months ( $p=0.2850$  and  $p=0.0698$ , respectively). When the repair was performed with conventional resin composite after 6 months, there was a significant association between the repair material and the fracture pattern ( $p=0.022$ ). Most of the conventional

Table 1: Information, Composition, and Manufacturers of Materials Used in this Study		
Material	Manufacturer	Composition <sup>a</sup>
Filtek Z350 XT High-viscosity conventional resin composite (HVC)	3M Oral Care, St Paul, MN, USA	Organic part: Bis-GMA, UDMA, TEGDMA, PEGDMA and Bis-EMA. Non-agglomerated silica nanoparticles 20 nm in size, non-agglomerated zirconia nanoparticles 4 to 11 nm in size, and combined zirconia (4 to 11 nm) and silica (20 nm) aggregated filler. The average size of the clusters ranged from 0.6 to 1 µm. The percentage of filler particles was 78.5% by weight and 63.3% by volume. Flexural strength: 165.14 MPa Flexural modulus: 11,348 MPa
Filtek Supreme XT Flow Low-viscosity conventional resin composite (LVC)	3M Oral Care, St Paul, MN, USA	Organic part: Bis-GMA, UDMA, TEGDMA, PEGDMA and Bis-EMA. Inorganic part: 65% by weight and 46% by volume. Composed of ytterbium trifluoride particles (0.1 to 5 µm), surface-modified and non-agglomerated 20 nm silica particles, surface-modified and non-agglomerated 75 nm silica particles, and silica nanoclusters (20 nm)/zirconia (4 to 11 nm) of modified surface (average nanocluster size from 0.6 to 10 µm). Flexural strength: 117.19 MPa Flexural modulus: 6410 MPa
Filtek One Bulk Fill High-viscosity bulk-fill resin composite (HVB)	3M Oral Care, St Paul, MN, USA	Organic matrix: AUDMA, Dimethacrylate AFM, UDMA, DDMA. Inorganic part: 20 nm silica particles (non-agglomerated/non-aggregated), 4-11 nm zirconia particles (non-agglomerated/non-aggregated), 100 nm ytterbium trifluoride, zirconia, and silica nanocluster. 76.5% by weight and 58.4% by volume. Flexural strength: ≈ 158 MPa Flexural modulus: ≈ 11.5 GPa (11,500 MPa)
Filtek Bulk Fill Flowable Restorative Low-viscosity bulk-fill resin composite (LVB)	3M Oral Care, St Paul, MN, USA	Organic matrix: Bis-GMA, low viscosity analogue of bisGMA (Procrylat), bis-EMA and UDMA. Inorganic part: zirconia/silica (0.01 to 3.5 µm), ytterbium fluoride (0.1 to 5 µm). 64.5% by weight and 42.5% by volume. Flexural strength: 126.5 MPa Flexural modulus: 4658 MPa
Single Bond Universal	3M Oral Care, St Paul, MN, USA	Bis-GMA, 2-hydroxyethyl methacrylate, silane-treated silica, ethyl alcohol, decamethylene dimethacrylate, water, 1,10-decanediol phosphate methacrylate, copolymer of acrylic and itaconic acid, camphorquinone, N,N-dimethylbenzocaine, 2-methacrylate dimethylaminoethyl, methyl ethyl ketone.
Relyx Ceramic Primer	3M Oral Care, St Paul, MN, USA	Ethyl alcohol, water, methacryloxypropyltrimethoxysilane.

Abbreviations: % by weight, percentage by weight; Bis-GMA, bisphenol-A glycidyl dimethacrylate; UDMA, urethane dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; Bis-EMA6, bisphenol A dimethacrylate polyethylene glycol dimethacrylate; AFM, addition-fragmentation monomer; AUDMA, aromatic urethane dimethacrylate; DDMA, 1,12-dodecane dimethacrylate; PEGDMA, polyethylene glycol dimethacrylate.

<sup>a</sup>The composition is presented according to data provided by the manufacturers. The flexural strength and flexural modulus values were extracted from the technical profiles of the materials available on the manufacturer's website. Approximate values (≈) were taken from graphs of the technical profile. The values are presented as "3M internal data", as shown in the technical profile.

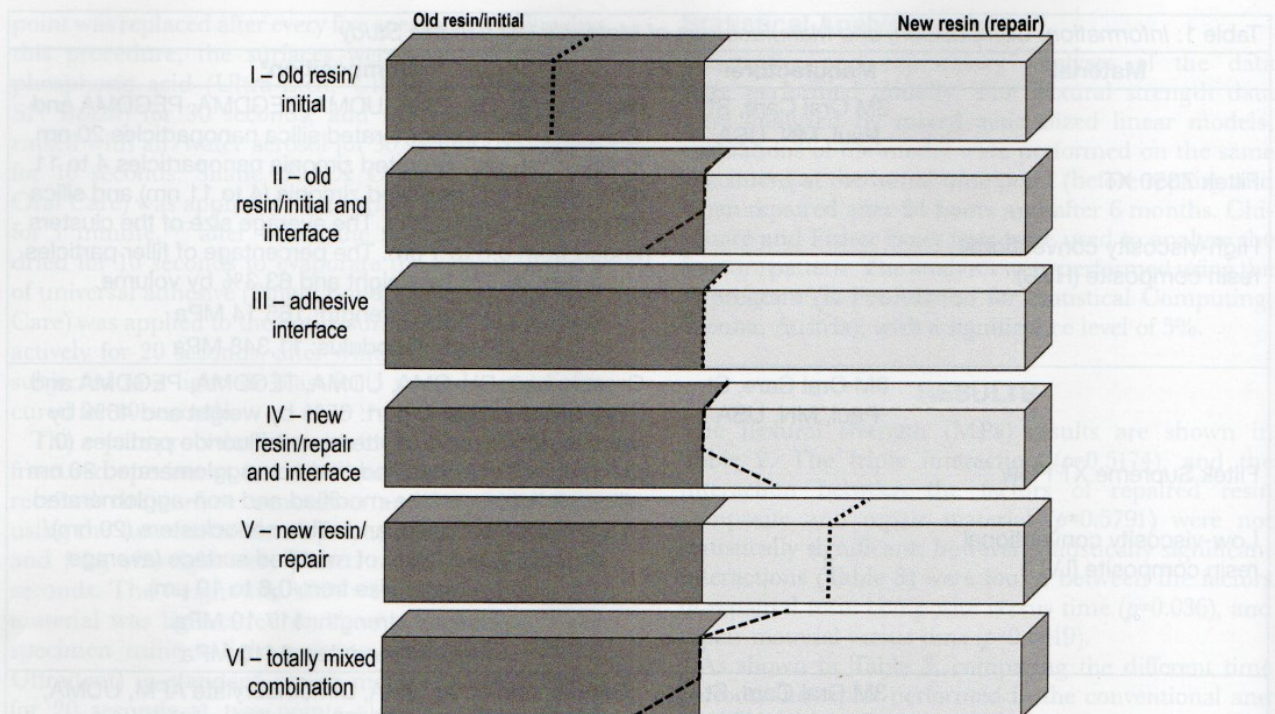


Figure 1. Fracture pattern classification used in the present study.

resin composite specimens repaired with bulk-fill materials at the 6-month time point were fractured at the adhesive interface with the old resin (HVB = 46.7%; LVB = 60%), or at the adhesive interface with the new resin (HVB = 46.7%). In addition, fractures involving old (conventional) resin were more frequent in repairs performed with bulk-fill composites, compared with those performed with conventional composites. Also observed was that 26.7% and 20% of the specimens, respectively, had mixed fractures (old and new resin and adhesive interface) when the conventional resin composites (HVC and LVC) were used to make the repair. Comparing the overall fracture frequency, regardless of the material used in the repair, the conventional resin composite showed a lower frequency (8.3%) of fractures at the adhesive interface, which increased slightly at the 6-month repair time (11.7%). On the other hand, the bulk-fill resin composite showed a higher frequency of failures at the adhesive interface after 24 hours (28.3%), which decreased at the 6-month time point (13.3%).

## DISCUSSION

Fundamentally, repair is considered a routine, minimal intervention procedure<sup>18</sup> that is effective in increasing the clinical survival of restorations.<sup>3</sup> However, doubts

still linger among professionals about the materials used in this procedure and the techniques for preparing the resin composite to be repaired.<sup>19</sup> When repairing restorations esthetically, the task of identifying the resin composite is a clinical challenge<sup>20</sup> since different brands, repair techniques, and resin types all influence both the bond strength of the repair, and the physicochemical properties of the materials involved.<sup>5,7,21</sup> The results of our study failed to reject the first null hypothesis since the initial restorative materials (conventional vs bulk-fill) did not differ in baseline flexural strength values. However, the second null hypothesis was rejected since the material used in the repair impacted the flexural strength values of the composite being repaired, especially when comparing the low- and high-viscosity resin composite groups, regardless of their respective conventional or bulk-fill characteristics.

The association of resin composites of different compositions is a common practice in the restoration procedure. With new patients, the materials used in previous restorations may not be known. The most common scientific approach is to use mostly adhesive tests<sup>16,22,23</sup> to investigate the behavior of the repairs, and to ultimately determine whether it is important to use the same resin as that used in the original restoration, or whether the resin type makes no difference. Newly

Table 2: Mean (Standard Deviation) for Flexural Strength (MPa) According to Resin Composite, Repair Material and Time (n=15)

Time Point	High-viscosity Resin Composite		
	Conventional	Bulk-fill	
Initial <sup>a</sup>	HVC	122.72 (40.15)	114.02 (33.45)
	LVC	127.89 (49.38)	115.83 (25.80)
	HVB	121.34 (41.05)	123.13 (35.09)
	LVB	135.17 (40.58)	112.34 (22.36)
	General mean	126.78 (42.21)	116.33 (29.18)
Repair performed with resin composite:			
After 24 hours	HVC	68.51 (39.83)	57.11 (27.28)
	LVC	78.60 (33.08)	79.71 (27.68)
	HVB	51.41 (24.30)	65.51 (38.20)
	LVB	74.25 (30.96)	87.80 (29.00)
Repair performed with resin composite:			
After 6 months	HVC	125.51 (60.07)	173.51 (76.84)
	LVC	190.12 (93.30)	226.63 (96.67)
	HVB	136.53 (71.05)	163.06 (81.75)
	LVB	207.50 (87.16)	198.21 (59.68)

Abbreviations: MPa, megapascals, HVC, high-viscosity conventional resin composite (Filtek Z350 XT); LVC, low-viscosity conventional resin composite (Filtek Supreme XT Flow); HVB, high-viscosity bulk-fill resin composite (Filtek One Bulk Fill); LVB, low-viscosity bulk-fill resin composite (Filtek Bulk Fill Flowable).

<sup>a</sup>The sample of high-viscosity conventional or bulk-fill resin composite without any repair performed.

polymerized resin composites have better chemical bonding potential than aged composites<sup>24</sup> because they have better potential to bond chemically to the bonding surface.<sup>7,21</sup> Aging of resin materials restricts the bond performance to its micromechanical

retention and decreases the chemical bond between the methacrylate radicals of the substrate and the resin used in the repair.<sup>23</sup>

Resin composite restorations for both anterior and posterior teeth are invariably subjected to considerable

Table 3: Comparison of Mean Flexural Strength Between the Resin-based Composites Grouped According to the Statistically Significant Interactions<sup>a</sup>

Repaired resin composite vs time (p=0.036)			
High-viscosity Resin Composite			
Conventional		Bulk-fill	
Time point	6 months > Initial > 24 hours	6 months > Initial > 24 hours	
Repair material vs time (p=0.0419)			
Time Point			
	Initial	After 24 hours	After 6 months
Repair material	Nonsignificant*	LVC, LVB > HVC, HVB	LVC, LVB > HVC, HVB

Abbreviations: HVC, high-viscosity conventional resin composite (Filtek Z350 XT); LVC, low-viscosity conventional resin composite (Filtek Supreme XT Flow); HVB, high-viscosity bulk-fill resin composite (Filtek One Bulk Fill); LVB, low-viscosity bulk-fill resin composite (Filtek Bulk Fill Flowable).

<sup>a</sup>Results of mixed generalized linear models (α=0.05); > indicates statistical significance.

\*Indicates nonsignificant differences at the initial time, before the specimens were repaired, and represent the initial resin composites.

Table 4: Distribution (Frequency) of Fracture Pattern According to Resin Composite, Repair Material, and Repair Time<sup>a</sup>

Resin Composite	Repair Time	Repair Material	Old Resin	Old Resin and Adhesive Interface	Adhesive Interface	New Resin and Adhesive Interface	New Resin	Mixed (Old, New, and Interface Resin)
Conventional	After 24 h	HVC	2 (13.3%)	4 (26.7%)	0 (0.0%)	7 (46.7%)	1 (6.7%)	1 (6.7%)
		LVC	0 (0.0%)	3 (20.0%)	2 (13.3%)	3 (20.0%)	1 (6.7%)	6 (40.0%)
		HVB	1 (6.7%)	4 (26.7%)	2 (13.3%)	5 (33.3%)	0 (0.0%)	3 (20.0%)
		LVB	1 (6.7%)	9 (60.0%)	1 (6.7%)	3 (20.0%)	1 (6.7%)	0 (0.0%)
	Total	4 (6.7%)	20 (33.3%)	5 (8.3%)	18 (30.0%)	3 (5.0%)	10 (16.7%)	
	After 6 mo	HVC	1 (6.7%)	3 (20.0%)	1 (6.7%)	5 (33.3%)	1 (6.7%)	4 (26.7%)
		LVC	0 (0.0%)	4 (26.7%)	2 (13.3%)	3 (20.0%)	3 (20.0%)	3 (20.0%)
		HVB	0 (0.0%)	7 (46.7%)	1 (6.7%)	7 (46.7%)	0 (0.0%)	0 (0.0%)
		LVB	1 (6.7%)	9 (60.0%)	3 (20.0%)	0 (0.0%)	1 (6.7%)	1 (6.7%)
	Total	2 (3.3%)	23 (38.3%)	7 (11.7%)	15 (25.0%)	5 (8.3%)	8 (13.3%)	
Bulk-fill	After 24 h	HVC	1 (6.7%)	4 (26.7%)	7 (46.7%)	2 (13.3%)	0 (0.0%)	1 (6.7%)
		LVC	1 (6.7%)	6 (40%)	5 (33.3%)	3 (20.0%)	0 (0.0%)	0 (0.0%)
		HVB	3 (20.0%)	5 (33.3%)	2 (13.3%)	1 (6.7%)	0 (0.0%)	4 (26.7%)
		LVB	0 (0.0%)	4 (26.7%)	3 (20.0%)	4 (26.7%)	1 (6.7%)	3 (20.0%)
	Total	5 (8.3%)	19 (31.7%)	17 (28.3%)	10 (16.7%)	1 (1.7%)	8 (13.3%)	
	After 6 mo	HVC	1 (6.7%)	4 (26.7%)	1 (6.7%)	5 (33.3%)	1 (6.7%)	3 (20.0%)
		LVC	5 (33.3%)	5 (33.3%)	1 (6.7%)	0 (0.0%)	1 (6.7%)	3 (20.0%)
		HVB	7 (46.7%)	3 (20.0%)	1 (6.7%)	3 (20.0%)	1 (6.7%)	0 (0.0%)
		LVB	2 (13.3%)	5 (33.3%)	5 (33.3%)	1 (6.7%)	1 (6.7%)	1 (6.7%)
	Total	15 (25.0%)	17 (28.3%)	8 (13.3%)	9 (15.0%)	4 (6.7%)	7 (11.7%)	

<sup>a</sup>The materials investigated were resin composites: aHVC, high-viscosity conventional resin composite (Filtek Z350 XT); LVC, low-viscosity conventional resin composite (Filtek Supreme XT Flow); HVB, high-viscosity bulk-fill resin composite (Filtek One Bulk Fill); LVB, low-viscosity bulk-fill resin composite (Filtek Bulk-Fill Flowable). The p-values found were conventional resin composite at 24 h ( $p=0.0997$ ), conventional resin composite at 6 months ( $p=0.0222$ ), bulk-fill resin composite at 24 h ( $p=0.2850$ ), and bulk-fill resin composite at 6 months ( $p=0.0698$ ).

flexural stress. The resistance of the restorative materials to this mechanical force is of great clinical relevance since the act of mastication subjects the tooth and restoration to different forces. The flexural strength test combines the forces of compression, shear, and traction.<sup>25</sup> The present study aimed to investigate the behavior of the resin material by analyzing the flexural strength of the repaired resin restorative materials, considering that the flexural strength test is a reliable mechanical test<sup>12</sup> that subjects the specimen to different forces until fracture, and that it represents a clinical condition similar to that of masticatory forces;<sup>25</sup> however, it is rarely used to study repairs,<sup>21</sup> especially in aged resin composite, or in repairs using materials of different viscosities.

The results of initial flexural strength testing of the unrepaired, intact materials showed no differences between conventional resin composite (Z350 XT) and

the high-viscosity bulk-fill product (Filtek One Bulk Fill). This could be attributed to their being materials made by the same manufacturer (3M Oral Care) and hence having similar inorganic composition (Table 1). In general, the mechanical properties of resins depend on the type and size of the filler particles.<sup>26</sup> Nanofilled resin composites can achieve a high filler content, and hence higher fracture resistance resulting from the reduced, nanometric size of the filler particles.<sup>26</sup> Both resin composites have a combination of silanized nanoclusters, nanofilled silica, and zirconia flagged individually (3M, Technical Profile); therefore, their load combination can increase the surface area of contact, thus providing high surface energy to the load-matrix relation and boosting the flexural strength values.<sup>27</sup>

In contrast, previous studies<sup>28,29</sup> have suggested that bulk-fill resin composite has slightly higher flexural strength values than conventional resin; however,

this difference may be associated with the specimen preparation methods, the analysis tests, the number of repetitions used in the study, and the conditions of storage. The present study was carried out in a completely randomized manner without excluding specimens, on account of the clinical impact of the manipulation and insertion of these materials. Thus, although International Organization for Standardization (ISO) 4049<sup>13</sup> was largely followed, some modifications were made in order to better study the repaired specimens, as described above. As predicted by the pilot study, higher values of standard deviation were expected, and the study was developed with a certain number of repetitions ( $n=15$ ); however, similar values of standard deviation or coefficient of variation were observed in other studies.<sup>21,30</sup> These modifications make it difficult to compare the initial values with those of previous studies. Nevertheless, other studies<sup>31,32</sup> also found differences between these two materials according to the storage medium or different specimen sizes. Regardless, the initial flexural strength values obtained by both materials exceeded the acceptable MPa values suggested by ISO 4049<sup>13</sup> as meeting flexural strength requirements. Overall, the final mean MPa values were lower in the present study than those suggested by the manufacturer. These values (Table 1) represent an overview, but they can change according to the marketed color and type (enamel, dentin, body) and do not accurately represent the products used in the present study.

After the repair was performed at 24 hours, the MPa values decreased regardless of the material used. The MPa values after 24 hours did not exceed the limits established by ISO 4049,<sup>13</sup> except for the repair performed on bulk-fill resin composite with low-viscosity bulk-fill material. These values could compromise the mechanical behavior of the immediately repaired restoration. It is important to view these results with caution since ISO values include non-repaired specimens made with the same material. When the resin-based materials are already polymerized, there are fewer carbon bonds (C=C) available to react with a new material.<sup>1</sup> Certain surface treatment protocols have been suggested to improve this situation, such as increasing mechanical retention and applying silane and/or adhesives with incorporated silane.<sup>4,24</sup> The application of phosphoric acid is important in repair procedures since it removes any organic contamination and residues left by the mechanical treatment, thus favoring the reaction between the silane and inorganic particles.<sup>7</sup> Abrasion or mechanical retention on the surface to be repaired increases the bond strength, compared with etching with phosphoric acid alone.<sup>1,7,25</sup>

Previous studies<sup>4,5,22</sup> have reported increased bond strength when using airborne-particle abrasion with aluminum, but a diamond point was used for thinning in this study because it is a treatment routinely used in clinical practice and because of its availability, technical simplicity, and proven effectiveness.<sup>7,20</sup> Moreover, a diamond point was used to create a plane surface at the interface so that the flexural strength test for repaired specimens could be conducted safely and correctly. Nevertheless, the use of airborne-particle abrasion must be evaluated in future studies, considering the beneficial effects that this procedure could promote.

The additional use of coupling agents such as silane remains an important step in resin composite repairs.<sup>17</sup> In the present study, these treatments were especially relevant in the 6-month aged composite, which obtained higher MPa values. Silane can be required especially for aged specimens that undergo some degradation of polymeric chains or exposure to and leaching of filler particles, events commonly reported with the use of polymeric materials.<sup>33,34</sup> In the present study, structural and chemical changes in the material may have increased the contact area, surface energy, and chemical affinity between the silane and the adhesive because of the mechanical action produced by the diamond point.

This finding is corroborated by the fracture pattern results, which indicate that no material had a frequency >50% of the failures strictly at the adhesive interface, regardless of the time under analysis. Nevertheless, considering the frequency of the fracture pattern, conventional resin composite showed a slight increase in fractures at the adhesive interface at the 6-month time period regardless of the material used in the repair; however, the bulk-fill resin composite showed a higher frequency of failure at the adhesive interface after 24 hours, decreasing with aging. The properties of aged material may have had some effect on the relationship between the repair material, silane, and adhesive. Filtek Bulk-Fill contains high-weight aromatic and addition-fragmentation monomers that decrease polymerization shrinkage,<sup>35</sup> which could improve the relaxation mechanism of the polymer network.<sup>34</sup> Moreover, bulk-fill resin composites have different incorporated initiators<sup>36</sup> and add tension between the inorganic composition of the resin and the resin matrix,<sup>29</sup> an outcome which could impact the reaction with the repair material.

Furthermore, storage in water for 6 months may have impacted the elastic modulus of the materials evaluated since it has been shown that water acts by reversing the initial stress arising from the inherent polymerization of the material and hence decreases the value of the dental

composite elastic modulus.<sup>34</sup> This is likely related to water absorption, release of unreacted monomers, and subsequent plasticization of the resin matrix.<sup>33</sup> Thus, a material with a lower elastic modulus is expected to produce less stress,<sup>34</sup> making it less rigid and more flexible in withstanding external loads.<sup>37</sup> The increase in MPa values could be associated with a delay in the propagation of cracks, which occurs in resinous materials in aqueous environments.<sup>38</sup> This mechanism is complex because the resistance needed to withstand fractures and the crack dissipation behavior involve delayed propagation of cracks in aqueous conditions, interface degradation, and matrix hydrolysis.<sup>38,39</sup> Thus, the results found should be interpreted with caution. Although an increase was observed in the flexural strength of the aged composite, a polymeric network compromised by the effects of either water or other biodegraders can be deleterious to other physical-chemical properties of the material.<sup>29,33,38,39</sup> In this respect, the difference found in the present study between immediate and aged repairs was also described by Imbery and others,<sup>21</sup> who reported that the association of mechanical and adhesive retention is beneficial under the flexural forces of repairs in aged resin but not in immediate repairs. Regardless of the repair time evaluated (immediate vs aged), the low-viscosity resin composites used herein obtained the highest values of flexural strength.

The type of resin composite is one of the main factors that influence the bond strength of the repair; therefore, it is suggested that the repair process be done with the same resin composite used to perform the original restoration.<sup>25</sup> However, the results presented in Table 2 and Table 3 do not completely support this recommendation since the highest MPa values were obtained for the flowable resins, but not in the group of repairs performed with the same resin composite used initially. It is worth noting that all the materials used in the study are from the same manufacturer; this facilitates chemical interactions between materials marketed for different clinical situations and could reduce the chances of chemical incompatibility between resin materials. Comparatively, universal adhesive (Single Bond Universal, 3M Oral Care) contains silane and chemical primers in its composition. These ingredients enhance the chemical bond on the surface of zirconia-based filler particles<sup>40</sup> and promote greater hydrophilicity, thus facilitating penetration into the surface of aged restorations.<sup>7,41</sup> Further studies should be designed to evaluate other commercial materials and manufacturers and investigate other methodologies and variables that may improve the clinical survival rate of restorations performed in resin composite. Moreover, the present study focused on the effect of

the viscosity and material type on repairs made with resin composites from a single manufacturer and did not evaluate the potential incompatibility of specimens repaired with materials from different manufacturers, an issue that still poses a challenge for professionals and researchers. Thus, new studies must be carried out to assess for this effect.

High-viscosity resin composites may have pores and bubbles incorporated during handling and application that would potentiate critical defects.<sup>42</sup> The greater flexural strength of the repair performed with fluid resins can be attributed to their composition (Table 1), which presents a percentage of relatively high-load particles, resilience, and the ability to withstand greater stress before fracture.<sup>32</sup> The higher values of resilience for flowable resin composites have been described previously,<sup>43,44</sup> associated with adequate flexural strength values; in this regard, Filtek Supreme XT Flow = 117.2 MPa<sup>45</sup> and Filtek Bulk-Fill Flowable = 127.89 MPa or 101.09 MPa,<sup>32</sup> for specimens stored in air versus artificial saliva, respectively, demonstrate greater crack propagation resistance. Moreover, according to the technical profile described by the manufacturer (Table 1), lower flexural modulus values are expected in low-viscosity materials. Bars repaired with the same material as the original restoration can withstand greater stresses than those repaired with two different materials, since the bars are flexed.<sup>25</sup> Overall, there is disagreement about what procedures should be used to repair restorations, especially those made using bulk-fill resin composites.<sup>1</sup>

## CONCLUSIONS

Considering the repair of conventional or bulk-fill resin composite from the same manufacturer (3M), the material to be repaired did not influence the flexural strength of the composite, although a decrease in fracture patterns at the adhesive interface occurred in the bulk-fill resin composite after aging. For this brand, low-viscosity resin composites used for repairs demonstrated higher flexural strength values compared to their high-viscosity counterparts.

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## CONFLICT OF INTEREST

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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## CONCLUSIONS

The study investigated the effect of water storage on the mechanical properties of bulk-fill resin-based composites. The results showed that water storage significantly affected the mechanical properties of the composites, particularly the flexural strength and modulus. The composites showed a decrease in flexural strength and modulus after water storage, which was attributed to the plasticization of the resin matrix. The degree of water sorption and the resulting plasticization were higher for the bulk-fill composites compared to the conventional composites. The findings of this study have important implications for the clinical use of bulk-fill resin-based composites. Clinicians should be aware of the potential for mechanical property changes in these materials when used in high-moisture environments, such as the oral cavity. Further research is needed to develop strategies to minimize the effects of water storage on the mechanical properties of bulk-fill resin-based composites.

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**CONFLICT OF INTEREST**

The authors declare that there is no conflict of interest regarding the publication of this article.

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