An investigation of the contribution of silane to the composite repair strength over time using a double-sided microtensile test

Federica Papacchini[1], Fabricio L.A. de Castro[2], Cecilia Goracci[1], Tálita N. Sardella[2], Franklin R. Tay[1,3], Antonella Polimeni[4], Marco Ferrari[1], Ricardo M. Carvalho[2]

Abstract

Purpose. To evaluate the contribution of silane application *vs* the application of a dentin adhesive only, to the composite repair strength over time using a double-sided testing design.

Methods. Twelve blocks of Herculite XRV (HC) were used as substrates. The opposing sides of each block were repaired with the same composite designated for that particular group. The repair composite was coupled to the substrate composite on one side using OptiBond Solo Plus (Sybron Kerr), while the other side was treated with RelyX silane primer (3M ESPE) prior to adhesive application. The repair composite was HC for Group 1 (HC-HC), Durafill VS (DF; Heraeus Kulzer) for Group 2 (HC-DF), Quadrant Anterior Shine (QAS; Cavex Holland BV) for Group 3 (HC-QAS) and Gradia Direct Anterior (GR, GC Corp.) for Group 4 (HC-GR). Microtensile bond strengths of the double-repaired blocks were evaluated after 24 hour- and 6 month-water storage. Data were analyzed with two-way ANOVA and Tukey's test (α=0.05). Student t-test for independent samples was used to compare, in each group and for both storage periods, bond strengths obtained for adhesive failures of the non-silanized and the silanized interfaces. *Results*. Material combination (p<0.001), storage time (p<0.001), interaction material-storage time (p<0.001) contributed significantly to the bond strength results. Only HC-DF after 6 month-storage exhibited a statistically higher bond strength on the silane-adhesive treated side when compared with the adhesive treated side. All other comparisons between silane-adhesive treated side and adhesive treated side were not statistically significant. HC-HC and HC-GR repairs exhibited cohesive failures in the substrate in both storage periods. Mixed failures occurred after 24 hour-storage only for HC-HC, HC-DF and HC-QAS repairs; no mixed failures occurred after 6 month-storage.

Clinical significance. There is no absolute advantage in using silane for repairing composites.

Short title: composite-composite bond strength over time

Keywords: composite, repair, silane, storage, double-side, microtensile bond strength

Introduction

Silane coupling agents are hybrid organic-inorganic compounds that promote adhesion between intrinsically different materials through chemical and physical interactions.[1,2] Silanization has been successfully employed in dentistry for coupling of glass fillers and matrix polymers in resin composites,[1,3] glass fibers and resin matrices in fiber-reinforced composite (FRC) posts,[4] fiber posts and resin composite cores,[5] and between ceramics and resin composites.[6-8]

Silane has also been advocated for composite repair with equivocal results. The use of a silane primer prior to a methacrylate-based adhesive as an intermediary agent for composite repair purportedly enhances the wetting and bonding of fresh resin composites to aged, worn, chipped or discolored composite substrates. Although some studies reported enhanced composite repair strengths when a silane primer was employed for composite repair, [9-11] such an improvement was found to be dependent upon the substrate chemistry and the surface treatment rendered.[12] Other studies showed that the sequential application of silane and bonding resin only improves composite repair strength marginally over that achieved with the bonding resin.[13-17]

Controversies also prevail regarding the stability of silane primers, as well as their durability in a wet, oral environment. Since resin composites are water permeable, hydrolyses of the silane-ceramic bond or silane-repaired composite bond may occur with time. Water storage and/or thermocycling were found to be detrimental for the silane-ceramic bond in some studies.[6,18] Conversely, increases in composite-ceramic strength after three months of water storage have also been observed.[7,8]

Direct comparisons of these results were not possible as the composite repairs were conducted under different conditions. It is anticipated that these issues may be resolved by using a double-sided composite repair design in which repairs made with adhesive only or with the sequential use of silane and a dentin adhesive were coupled to the same repair composite and challenged under the same experimental criteria.

[1]*Department of Dental Materials, University of Siena, Policlinico Le Scotte, Viale Bracci, Siena 53100, Italy.* [2]*Department of Prosthodontics, Integrated Center for Research (CIP-I), Bauru School of Dentistry, USP, Al. Dr. Octavio Pinheiro Brisolla 9-75, CEP 17012-901, Bauru, SP, Brazil.*

[3]*Department of Oral Biology & Maxillofacial Pathology, School of Dentistry, Medical College of Georgia, Augusta, Georgia, 30912-1129, USA.*

[4] *Department of Pediatric Dentistry, Università 'La Sapienza', Roma, Italy*

Corresponding Author:
Prof. Marco Ferrari,
University of Siena, School of Dental Medicine,
Department of Dental Sciences,
Policlinico Le Scotte, Viale Bracci, Siena, 53100, Italy
Phone: +39.0577.233131, Fax: +39.0577.233117,
E-mail: ferrarimar@unisi.it

Moreover, as composite repairs are often performed clinically without knowing the nature of the original substrate composite, both homogeneous repair (i.e. repair performed using a composite that is identical to the original substrate) and heterogeneous repairs (i.e. repairs with different composites) were examined in this study.

The objective of this *in vitro* study was to evaluate the contribution of silane to the composite repair strengths in both homogeneous and heterogeneous repairs after 24 hours and after a 6 month-water storage period. The null hypothesis tested was that there are no differences in the 24 hours and 6 month composite repair strengths of dentin adhesive-mediated homogeneous and heterogeneous composite repairs irrespective of whether silane is used as an intermediary coupling agent.

Materials and Methods
Specimen Preparation

The materials used in this study and their compositions are listed in Table 1. A silicone mold was used to prepare 12 blocks of Herculite XRV composite (HC; Sybron Kerr, Orange, CA, USA). These composite blocks, each measuring 1 x 1 x 0.3 cm, were used as the substrate material in all the experimental groups. Each block was prepared by carefully condensing 1

Table 1. *Materials used in this study, their respective compositions, batch numbers and manufacturers (Abbreviations: Bis-GMA: bisphenol A diglycidylmethacrylate; TEGDMA: triethylenglycol dimethacrylate; UDMA: urethane dimethacrylate; GPDM: glycerophosphate dimethacrylate; HEMA: 2-hydroxyethyl methacrylate).*

| Materials	Composition	Batch no.	Manufacturer
Herculite XRV	Bis-GMA, fillers (0.60 Ìm, 59 vol.%)	A1:206127 A3:207212	Kerr Co., Orange, CA, USA
Durafill VS	Bis-GMA, TEGDMA,UDMA, colloidal silica, prepolymerized filler (0.02-0.04 _m, vol. unknown)	A3:030136	Heraeus Kulzer, Hanau, Germany
Quadrant Anterior Shine	Bis-GMA, acrylates, barium glass, silica, silicate glass, fluoride containing fillers (0.7 _m, 63 vol.%)	A3:0305231	Cavex Holland BV, Haarlem, The Netherlands
Gradia Direct Anterior	UDMA, dimethacrylate co-monomers, silica (22 vol.%), prepolymerized filler (0.85 _m, 42 vol.%), pigments, catalysts	A3:020026C	GC Corp., Tokyo, Japan
OptiBond Solo Plus	Bis-GMA, HEMA, GPDM, sodium fluorosilicate, photoinitiators, fillers[a], ethanol, water	4 – 1023	Kerr Co., Orange, CA, USA
RelyX silane primer	Silane < 1%, ethanol 70-80%, water 20-30%	NA	3M/ESPE, St. Paul, MN, USA

[a] *A mixture of barium aluminium borosilicate glass, fumed silica, and disodium hexafluorosilicate glass (26 wt%).*

mm-thick incremental layers of the hybrid composite into the mold. Light-cured of each composite increment was performed over the entire surface for 40 s with the largest tip of a visible light curing unit (Gnatus Fotopolimerizador, Gnatus, São Paulo, Brazil) at 450 mW/cm^2. Prior to polymerizing the last layer, a clear celluloid sheet and a glass slab were placed over the composite to create a flat surface. After curing the top surface, the specimen was removed from the mold and further light-cured from the base for an additional 40 s to ensure optimal polymerization.

Each block of Herculite XRV was stored in 20 mL of distilled water at 37°C for one week before the repairs were performed. They were then randomly assigned to four groups of three specimens each, with each group differing in the composite employed for the repair procedure.

In Group 1 (HC-HC) the Herculite XRV blocks were repaired with the same composite and served as the control homogeneous repair group with which the other three heterogeneous repair groups were compared. In Group 2 (HC-DF), a microfilled composite, Durafill VS (Heraeus Kulzer, Hanau, Germany), was used as the repairing material. In Groups 3 (HC-QAS) and 4 (HC-GR), two microhybrid composites, Quadrant Anterior Shine (QAS, Cavex Holland BV, Haarlem, The Netherlands) and Gradia Direct Anterior (GC Corp., Tokyo, Japan), were used respectively as the heterogeneous repair composites. Cohesive strengths of unrepaired Herculite XRV blocks (designated as Group 0) were also evaluated separately after 24 hours and 6 months.

A double-sided bond testing design was employed for the repair procedures (Figure 1). For each group, the opposing
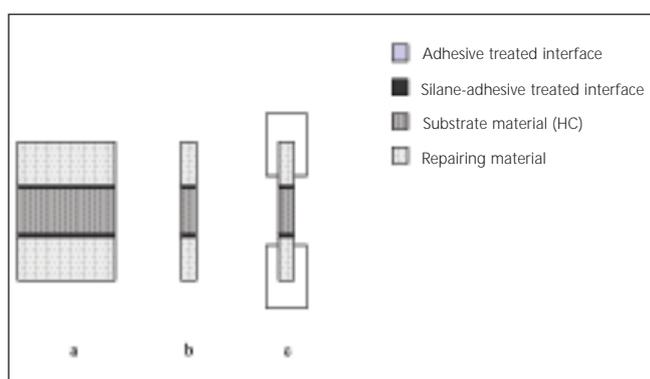
Figure 1. Procedure for the preparation of double-sided bonded microtensile specimens. A block of Herculite XRV (HC) was repaired on the opposing surfaces with a resin composite that was either the same or a different composite. A different intermediary agent was used for each side (a). For the repairing material a different shade from that of the substrate was chosen. By means of a water cooled diamond saw, the composite build-up was serially sectioned into multiple double-side sticks (b), composing of two ends of repairing material bonded to the central block of the substrate material. Each specimen was glued by the ends to the fixtures of a universal testing machine and then stressed in tension at a speed of 0.5 mm/min (c) until failure occurred.

surfaces of each substrate block were repaired with the same composite designated for that group. However a different intermediary agent was used on each side for coupling of the repair composite to the original composite. Prior to the application of the intermediary agents, the surfaces to be repaired were abraded with a fine grit diamond bur (#2135F) for 10 s under copious water irrigation, to simulate the clinical removal of a thin layer of an old restoration. A new diamond bur was used for each group. The abraded surfaces were cleaned with a 37% phosphoric acid gel (Scotchbond etchant, 3M ESPE Dental Products, St. Paul, MN, USA) for 30 s. They were rinsed with water for 30 s, and dried with oil-free compressed air for 10 s from a distance of 5 mm.

On one side of each block, a thin layer of dentin adhesive (OptiBond Solo Plus, Sybron Kerr) was applied with a microbrush and light cured for 20 s. The other side of each block was first treated with RelyX silane primer and allowed to air-dry for 1 min at room temperature, before applying the OptiBond Solo Plus adhesive. After the application of these intermediary coupling agents, a repair composite was applied and light-cured in 1 mm-thick increments, creating 4 mm thick layers of the repair composite on both sides of the original composite block. A different shade of the repair composite was utilized in order to distinguish it from the substrate composite during bond testing and subsequent evaluation of the location of failure. In addition, two nail varnishes of different colours were used to identify the intermediary agents used for the opposing repair builds-ups.

After storing in distilled water at 37°C for 24 h, each repaired block was serially sectioned in both *x* and *y* directions perpendicular to the bonded surfaces by means of a slow-speed diamond saw (Isomet, Buehler Ltd., Lake Bluff, IL, USA) to produce several 1-cm long sticks with a cross-sectional area of approximately 0.5 mm^2. Each block of material produced about 22-25 testable sticks. Each stick was composed of the repair composite at both ends that were bonded to the central block of the original composite. This protocol enabled the two coupling techniques (silane and adhesive *vs* adhesive only) to be simultaneously challenged to the tensile load and compared under the same testing condition.

Half of the specimens (i.e. about 35 sticks for each group) were tested 24 h after sectioning. The other half of the specimens were stored in sealed vials of distilled water containing 0.1% sodium azide at 37°C and were tested after 6 months of storage.

Composite repair strength

The "non-trimming" version of microtensile bond testing technique[19] was employed for evaluating composite repair strength. Each stick was glued via the ends to the fixtures of a universal testing machine (DL500, EMIC, São José dos Pinhais,

PR, Brazil) using a cyanoacrylate adhesive (Model Repair II Blue, Dentsply-Sankin K.K., Japan). Care was taken to position the double interface in the middle of the space between the fixture, in order to stress the specimen uniformly. A tensile load was applied at a cross-head speed of 0.5 mm/min, until specimen failure occurred. The load at failure was recorded in Kgf and the fractured fragments were recovered from the fixtures with a scalpel blade. The cross-sectional area at the site of failure was measured to the nearest 0.01 mm with a digital caliper (500-143B, Mitutoyo Sul Americana Ltda., Suzano, SP, Brazil). The microtensile strength was calculated by dividing the maximum load at failure (Kgf) by the cross-sectional area (cm^2) and converted to MPa. For each debonded stick, the fractured surfaces were observed under an optical microscope (Stereoscopic Microscope, Laborama, São Paulo, Brazil) at 40X magnification to identify the failure mode. Failure modes were classified as adhesive, cohesive and mixed failures. In addition, depending on the exact location of the failure, five types of failure sites were distinguished (Figure 2).

Group 0 - Cohesive strength of the unrepaired composite substrate

Three additional blocks of unrepaired Herculite XRV, measuring 1 x 1 x 1 cm, were prepared by incremental light curing in a silicone mold and designated as Group 0. The blocks were stored in distilled water at 37° C for 1 week and then serially sectioned to obtain composite sticks measuring 1 cm x 1 mm x 1 mm.

Each stick was carefully trimmed from two sides along the
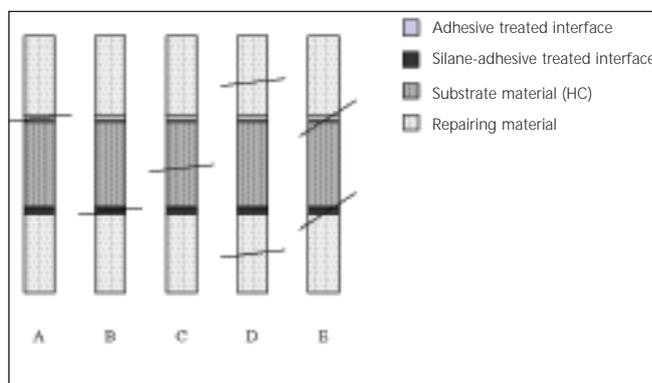
Figure 2. Schematic representation of the site of failure for the double-sided microtensile specimen. Site A: failure involving the composite-composite interface at the side that was treated with the bonding agent only. Site B: failure involving the composite-composite interface at the side that was treated with a silane primer followed by the bonding agent. Site C: failure involving the substrate material. Site D: failure involving the repairing material at any side. Site E: failure along sites that were not included in the previous four classifications. Sites of failure may be further classified by the mode of failure into adhesive (A,B), cohesive (C,D) or mixed failure (E).

middle third of the stick using an ultra-fine diamond bur mounted on a high-speed handpiece. By reducing the cross-sectional area to a 'neck' of approximately 0.5 mm^2, a dumbbell-shaped specimen was created for evaluation of the cohesive strength of the virgin, unrepaired composite. The trimming was performed in order to reduce the cross-sectional area to the same cross-sectional area of the repaired specimens (i.e., 0.5 mm^2), and make them comparable. Additionally, previous experience in testing untrimmed, stick specimens of resin composite showed that the composite cohesive strength

Table 2. *Means and standard deviations (SD) of the microtensile bond strength (-TBS) values differentiated by mode and site of failures, measured in each experimental group after 24 hour- and 6 month-water storage. §Means and standard deviations (SD) of the pooled data for all sticks in each group at both storage period are also reported. Numbers in square brackets represent the number of double-sided bonded sticks that were tested per group (N). -HC represents the cohesive strength of the unrepaired substrate (HC).*

				TBS (MPa)				
				Failure mode				
				Adhesive		Cohesive		Mixed
	Groups	N	Mean§	A	B	C	D	E
24h								
0	-HC	[15]	63.8 (15.5)					
1	HC-HC	[33]	46.4 (17.5)	46.6 (17.9)	49.3 (20.2)	53.8 (14.8)	32.2 (3.9)	33.5 (8.5)
2	HC-DF	[35]	42.2 (7.6)	41.7 (6.6)	44.9 (8.5)	-	40.7 (7.7)	37.6 (9.8)
3	HC-QAS	[34]	45.1 (12.3)	48.0 (13.6)	49.6 (10.1)	-	39.6 (9.1)	30.6 (2.8)
4	HC-GR	[37]	48.7 (12.4)	50.9 (12.4)	52.8 (10.8)	46.4 (8.8)	42.1 (13.5)	-
6 mos								
0	-HC	[18]	68.4 (13.6)					
1	HC-HC	[31]	39.3 (12.7)	(12.7)	36.6 (12.6)	44.0 (13.9)	38.7 (14.0)	-
2	HC-DF	[35]	22.6 (9.4)	20.8 (9.3)	29.8 (7.7)	-	17.9 (5.5)	-
3	HC-QAS	[32]	21.2 (5.8)	20.0 (6.3)	23.4 (5.2)	-	21.4 (5.4)	-
4	HC-GR	[31]	36.7 (12.3)	36.3 (15.2)	35.0 (12.7)	36.4 (2.8)	41.2 (7.8)	-

Table 3. *Percentage of failure differentiated by the failure mode and site of the double-sided composite repairs after 24 hour- and 6 month-water storage.*

		Percentage of failure (%)				
		Failure mode				
		Adhesive		Cohesive		Mixed
Groups	N	A	B	C	D	E
24 h						
1	HC-HC	39.4	30.3	15.2	9.1	6.0
2	HC-DF	34.3	31.4	-	28.6	5.7
3	HC-QAS	44.1	23.5	-	26.5	5.9
4	HC-GR	35.2	29.7	8.1	27.0	-
6 mos						
1	HC-HC	38.7	19.4	16.1	25.8	-
2	HC-DF	65.7	22.9	-	11.4	-
3	HC-QAS	50.0	25.0	-	25.0	-
4	HC-GR	35.5	38.7	6.4	19.4	-

usually surpass the ability of the cyanoacrylate glue to hold the specimen glued to the fixtures of the testing machine, thus causing debonding from the fixtures.[20] By trimming the middle of the specimen to a neck, relatively larger areas are available to glue the ends to the fixtures and lower loads are required to cause failure. This warrants the actual testing of the cohesive strength of the composite.

The trimmed specimens were observed at 40X magnification under a stereoscopic microscope to ensure that they were free of air bubbles or other defects. Imperfect specimens were discarded.

Half of the specimens were tested immediately after sectioning to determine the one week-cohesive strength of the unrepaired composite. The other half of the specimens were stored in sealed vials containing distilled water at 37°C and tested after 6 months of water storage. For each testing period, the specimens were loaded in tension until failure as described previously.

Statistical Analysis

The bond strength data differentiated by five sites of failure (Figure 2) were first analyzed with the Kolmogorov-Smirnov test for normality and the Levene median test for equal variance. Subsequently, a two-way ANOVA was applied with "bond strength" as the dependant variable, "material combination" and "time" as factors. Tukey's test was then used for multiple comparisons among the tested factors.

In addition, Student t-test for independent samples was used to compare, in each group and for both storage periods, the bond strength data obtained for adhesive failures of the non-silanized (i.e. failure site A; Figure 2) and the silanized

interfaces (i.e. failure site B; Figure 2). All analyses were performed using SPSS 11.0 software (SPSS, Chicago, IL, USA), with significance set at the 95% probability level.

Results

No premature failures occurred in the tested specimens, irrespective of intermediary agent used, materials combination and storage time. The means and standard deviations of the microtensile bond strengths for each experimental group after 24 hours and 6 months of water storage, including composite repair strengths differentiated by the sites of failure, are shown in Table 2. The percentages of failure, classified as adhesive (in the adhesive or silane-adhesive treated side), cohesive (in the substrate or the repaired composite) or mixed for each material combination and storage period are shown in Table 3.

Two-way ANOVA revealed that both "material combination" (p<0.001), "storage time" (p<0.001) and the interaction of these two factors (p<0.001) significantly influenced composite repair strength.

The statistically significant differences in bond strengths of the eight experimental groups as differentiated by the materials combination and storage time are shown in Figure 3. Regardless of the storage time, HC-HC and HC-GR repairs acquired significantly higher bond strengths than the other two material combinations, which were statistically comparable (Figure 4). Also, irrespective of the material combination, bond strengths at 24 hours were significantly higher than the corresponding bond strengths after 6 months of water storage (Figure 5).

In addition, there were significant differences in composite repair strength among the different types of failure (p = 0.01,
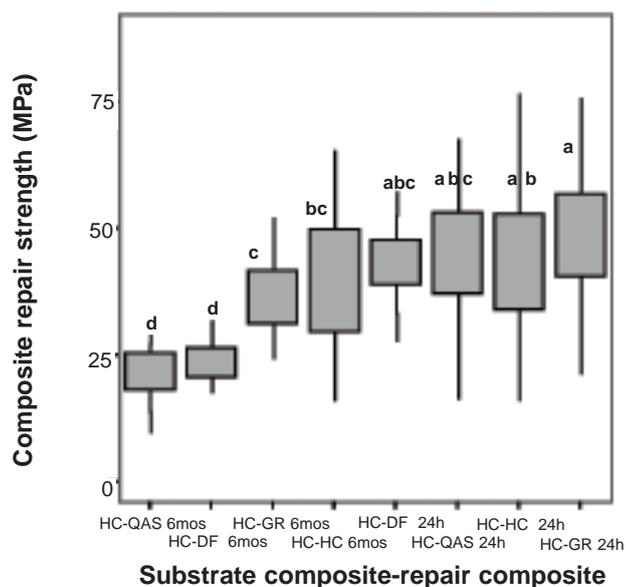
Figure 3. Box-chart showing the microtensile bond strengths (MPa) of the eight experimental groups as differentiated by the material combination and storage time. The length of each box represents the interquartile range of the bond strengths measured for each composite repair at a particular storage period. Boxes labelled with the same letters are not statistically different (p>0.05).
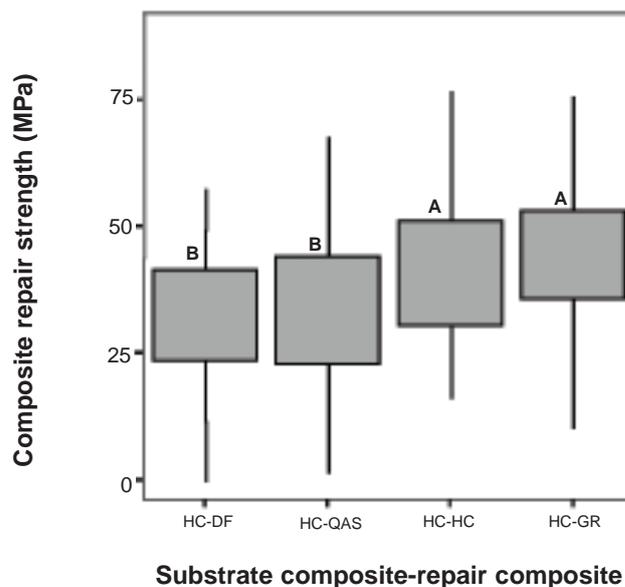

Figure 4. Box-chart showing the microtensile bond strength (MPa) of the pooled data from each group, regardless of the storage time and the mode or site of failure. The length of each box represents the interquartile range of the bond strengths measured for each repair. Boxes labeled with the same letters are not statistically different (p>0.05).

Figure 6). Regardless of the other dependant variables, strengths obtained for cohesive substrate failures (i.e. failure site C - Figure 2) were comparable with the composite repair strengths in specimens that exhibited adhesive failures along the silane-adhesive treated side (i.e. failure site B - Figure 2). These values, in turn, were significantly higher than those of the other types of failures, that were themselves statistically comparable (p<0.05). When t-tests were used to compare the adhesive failures (i.e. failure sites A and B - Figure 2) separately for each group and storage period, only the HC-DF 6-month water storage group exhibited a significantly higher repair strength on the silane-adhesive treated side (p = 0.02). All other comparisons between the silane-adhesive treated side and adhesive treated side were not statistically significant.

Discussion

The double-sided microtensile bond testing design provides a means by which composite repairs using an adhesive only or the sequential use of silane and an adhesive may be evaluated simultaneously in a single stick under the same testing condition. When conventional bond testing is used, the data for the two repair protocols have to be derived separately under slight variations of the testing conditions that are difficult to standardize. By using the double-sided approach, the treatment regime that outperforms the other can be readily discerned without even considering the actual repair strength values. This helps to eliminate potentially variables such as minor variations in the alignment angulations of the bonded sticks along the fixtures of a universal testing machine, or the influence of variable amounts of cyanoacrylate glue along the ends of different specimens. This testing technique

has previously been used to simultaneously compare the bond strengths of resin composites to superficial and deep dentin.[21] In that study, a dentin disc with one side representing superficial dentin and the other side representing deep dentin were bonded to composite blocks using the same dentin adhesive, so that the probability of failure between superficial and deep dentin could be readily compared.

Bouschlicher et al[12] found that silane does not enhance the repair strength of a microfilled composite, as the small size of filler particles can limit the effectiveness of silane application. Thus, the hybrid composite Herculite XRV was used as the composite substrate for repair. As the adhesive failures that occurred on the non-silanized side (failure site A) and the silanized side (failure site B) of the repaired composites yielded similar repair strengths, we have to accept the hypothesis that the use of silane prior to the bonding agent has no effect on composite repair strength after 24 hour- and 6 month-water storage.

Chemical treatment of bur-roughened composite substrate with 37% phosphoric acid, as performed in similar research protocols,[22,23] aimed to clean the bonding surface from smears and debris produced by mechanical treatment.[24] The effect of acid etching on resin composite substrate is probably a superficial decontamination, so as to enhance the surface energy and allow for an increased wetting of the intermediary agent to the substrate, without creating any morphologic changes in the retentive pattern of the resin matrix.[23]

Bond strength of composite to freshly-placed composite has been demonstrated to be the same as the cohesive strength of the original composite.[25] Conversely, composite repairs performed on aged composites in which no active free radicals
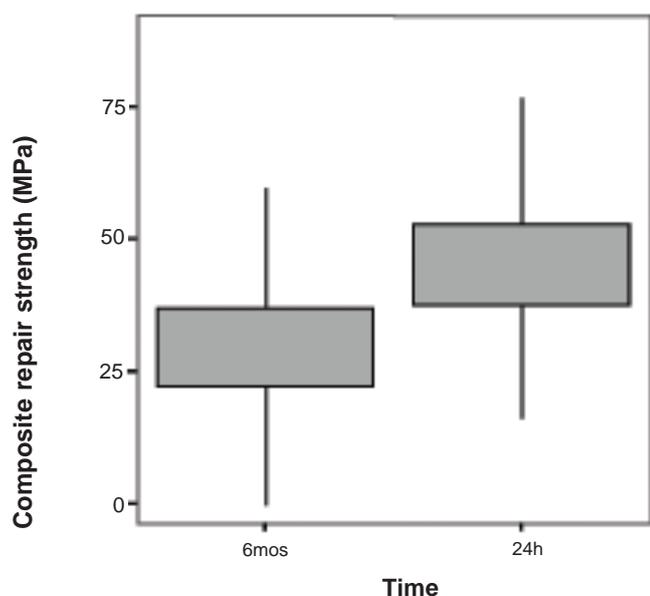
Figure 5. Box-chart showing the microtensile bond strength (MPa) of the pooled data from all groups to examine the effect of the storage time on composite repair strength, irrespective of the materials combination and sites of failure. The overall composite repair strength after 24 hours of water storage was significantly higher than that after 6 months of water storage.
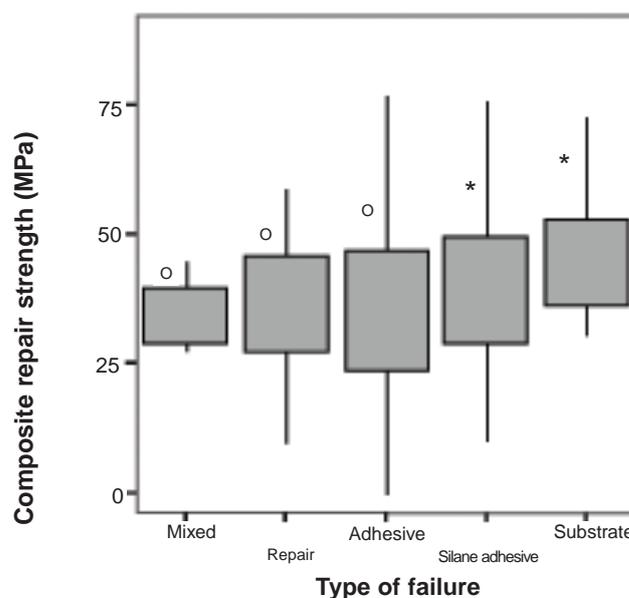
Figure 6. Box-chart showing the microtensile bond strength (MPa) of the pooled data from all groups, to examine composite repair strengths as differentiated by their site of failure, regardless of material combinations and storage time. The length of each box represents the interquartile range of the bond strengths measured for each site of failure. Boxes labeled with the same symbol are not statistically different (p>0.05).

exist for coupling generally yielded 19-80% of the original composite cohesive strength.[13,15,16,25,26] This wide variability reflects the differences in treatment and testing protocols used for composite repairs. In the present study, composite repairs strengths determined at 24 hours after silanization ranged from 70% (HC-DF) to 83% (HC-GR) of the cohesive strength of the substrate composite. Conversely, when the dentin adhesive was solely employed as the coupling agent, the composite repaired strengths ranged from 65% (HC-DF) to 78% (HC-GR) of the cohesive strength of the substrate composite.

A general decrease in composite repair strength was evident in both the silanized or non-silanized interfaces after 6 months of water storage. For the silanized side, composite repair strengths dropped from the original 70-83% at 24 hours to 34-53% of the cohesive strength of the substrate composite after 6 months. Similarly, for the non-silanized side, these values were reduced from the original 65-78% at 24 hours to 29-57% of the composite cohesive strength after 6 months. These results indicated that irrespective of whether composite repair was accomplished using a dentin adhesive or in conjunction with silane, the repaired composite-composite bond deteriorated with time.

Water sorption in the oral environment[27] plays a key role in the hydrolytic degradation of resin composites.[28] Adsorbed water can induce softening and dissolution of the matrix, microcrack formation and debonding of the filler-matrix interfaces.[29] Some studies have addressed the effect of water storage on composite repair bond strength.[15,22,30] Although there were differences in bond strength over the 1 month-storage,[22,30] they were not statistically significant. Conversely, Söderholm & Roberts[15] reported that composite repair has a

significant tendency to weaken after 3 months and 1 year of water storage. In the present investigation, storage time was a significant factor that affects composite repair strength, as the pooled data at 6 months were significantly lower than those measured at 24 hours.

Homogeneous and heterogeneous repairs were also investigated in this study. It has been suggested that composite repair bond strengths greater than 18 MPa are required to resist stresses derived from occlusal function and to produce clinically acceptable results.[23] Although the repair strengths from all groups exceeded 18 MPa even after 6 months of water storage, one has to interpret these results with caution, as it is inappropriate to compare repair strengths that were derived from different testing methods. As clinicians who perform with composite repairs may not be aware of the nature of the existing composite substrate, the ability to produce satisfactory composite repairs using dissimilar materials is clinically important and warrants further research.

Besides bond strength, interfacial sealing is also important in composite repairs in order to prevent microleakage, leading to bond deterioration and failure over time.[14] Interfacial staining, as a result of an imperfect seal, may drastically compromise esthetics, especially in anterior teeth, and require replacement of the entire restoration. A recent study,[24] aimed to evaluate the effects of different surface treatments on interfacial microleakage of adhesive-mediated composite repairs, showed that the resin bonding agent, irrespective of surface roughening, is the main factor promoting the sealing ability of the repaired composite. In the present investigation, the preliminary application of a silane coupling agent prior to adhesive resin demonstrated no advantage in terms of bond strength repair over a period of 6 months. However, the long-

term sealing ability of silane-treated repairs compared to that of adhesive-mediated repairs should be investigated.

References

1. Plueddemann EP. *Silane coupling agents, 2nd ed.* New York, USA: Plenum Press; 1991.

2. Matinlinna JP, Lassila LVJ, Özcan M, Yli-Urpo A, Vallittu PK. An introduction to silanes and their clinical applications in dentistry. *Int J Prosthod* 2004; 17: 155-164.

3. Lin CT, Lee SY, Keh ES, Dong DR, Huang HM, Shih YH. Influence of silanization and filler fraction on aged dental composites. *J Oral Rehabil* 2000; 27: 919-926.

4. Debnath S, Wunder SL, McCool JI, Baran GR. Silane treatment effects on glass/resin interfacial shear strengths. *Dent Mater* 2003; 19: 441-448.

5. Goracci C, Raffaelli O, Monticelli F, Balleri B, Bertelli E, Ferrari M. The adhesion between prefabricated FRC posts and composite resin cores: microtensile bond strength with and without post-silanization. *Dent Mater* 2005; 21: 437-444.

6. Roulet JF, Söderholm K-JM, Longmate J. Effect of treatment and storage conditions on ceramic/composite bond strength. *J Dent Res* 1995; 74: 381-387.

7. Berry T, Barghi N, Chung K. Effect of water storage on the silanization in porcelain repair strength. *J Oral Rehabil* 1999; 26: 459-463.

8. Hooshmand T, van Noort R, Keshvad A. Storage effect of a pre-activated silane on the resin to ceramic bond. *Dent Mater* 2004; 20: 635-642.

9. Matsumura H, Hisamatsu N, Atsuta M. Effect of unfilled resins and a silane primer on bonding between layers of a light-activated composite resin veneering material. *J Prosthet Dent* 1995; 73: 386-391.

10. Tezvergil A, Lassila LVJ, Vallittu PK. Composite-composite repair bond strength: effect of different adhesion primers. *J Dent* 2003; 31: 521-525.

11. Özcan M, Alander P, Vallittu PK, Huysmans MC, Kalk W. Effect of three surface conditioning methods to improve bond strength of particulate filler resin composites. *Journal of Materials Science: Materials in Medicine* 2005; 16: 21-27.

12. Bouschlicher MR, Reinhardt JW, Vargas MA. Surface treatment techniques for resin composite repair. *Am J Dent* 1997; 10: 279-283.

13. Azarbal P, Boyer DB, Chan KC. The effect of bonding agents on the interfacial bond strength of repaired composites. *Dent Mat* 1986; 2: 153-155.

14. Saunders WP. Effect of fatigue upon the interfacial bond strength of repaired composite resins. *J Dent* 1990; 18: 158-162.

15. Söderholm K-JM, Roberts MJ. Variables influencing the repair strength of dental composites. *Scand J Dent Res* 1991; 99: 173-180.

16. Swift EJ, Cloe BC, Boyer DB. Effect of a silane coupling agent on composite repair bond strength. *Am J Dent* 1994; 7: 200-202.

17. Brosh T, Pilo R, Bichacho N, Blutstein R. Effect of combinations of surface treatments and bonding agents on the bond strength of repaired composites. *J Prosthet Dent* 1997; 77: 122-126.

18. Gregory WA, Hagen CA, Power JM. Composite resin repair of porcelain using different bonding materials. *Oper Dent* 1988; 13(3): 114-118.

19. Sano H, Shono T, Sonoda H, Takatsu T, Ciucchi B, Carvalho RM, Pashley DH. Relationship between surface area for adhesion and tensile bond strength. Evaluation of a micro-tensile bond test. *Dent Mater* 1994; 10: 236-240.

20. Mendonça JS, Souza Jr. MHS, Carvalho RM. Effect of storage time on microtensile strength of polyacid-modified resin composites. *Dent Mater* 2003; 19: 308-312.

21. Fernandes CA. Estudo comparativo de resistência adesiva à dentina superficial e profunda testada simultaneamente, empregando-se dois sistemas adesivos. PhD Thesis, Bauru, SP, Brazil, 2000.

22. Shahdad SA, Kennedy JG. Bond strength of repaired anterior composite resins: an in vitro study. *J Dent* 1998; 26: 685-694.

23. Lucena-Martín C, González-López S, Navajas-Rodríguez de Mondelo JM. The effect of various surface treatments and bonding agents on the repaired strength of heat-treated composites. *J Prosthet Dent* 2001; 86: 481-488.

24. Cavalcanti AN, Lobo MM, Fontes CM, Liporoni P, Mathias P. Microleakage at the composite-repair interface: effect of different surface treatments methods. *Oper Dent* 2005; 30 (1): 113-117.

25. Boyer DB, Chan KC, Torney DL. The strength of multilayer and repaired composite resin. *J Prosthet Dent* 1978; 39: 63-68.

26. Mitsaki-Matsou H, Karanika-Kouma A, Papadoyiannis Y, Theodoridou-Pahine S. An in vitro study of the tensile strength of composite resins repaired with the same or another composite resin. *Quintessence Int* 1991; 22: 475-481.

27. Örtengren U, Andersson F, Elgh U, Terselius B, Karlsson S. Influence of pH and storage time on the sorption and solubility behavior of three composite resin materials. *J Dent* 2001; 29: 35-41.

28. Söderholm K-JM, Zigan M, Ragan M, Fischlschweiger W, Berhgam M. Hydrolytic degradation of dental composites. *J Dent Res* 1984; 63: 1248-1254.

29. Ferracane JL, Marker VA. Solvent degradation and reduced fracture toughness in aged composites. *J Dent Res* 1992; 71: 9-13.

30. Sau CW, OH GSY, Koh H, Chee CS, Lim CC. Shear bond strength of repaired composite resins using a hybrid composite resin. *Oper Dent* 1999; 24: 156-161.