Initial Repair Bond Strength of a Nano-filled Hybrid Resin: Effect of Surface Treatments and Bonding Agents

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ABSTRACT

Background: The optimal surface treatment is an important factor in repairing failed restorations.

Purpose: The aim of this study was to compare the effect of different surface treatments in combination with bonding agents on the repair of an aged nano-filled resin composite.

Materials and Methods: Resin composite disks (N = 180; Filtek Supreme XT, 3M ESPE, St. Paul, MO, USA), 6 mm in diameter and 2 mm in height, were prepared. After accelerated aging of 300 hours in a weathering tester, the specimens were randomly divided into six groups of 30 each, according to the following surface treatment methods: no surface treatment (control group, C), 38% phosphoric acid gel (PA), 9.6% hydrofluoric acid gel (HF), abrasion with sodium bicarbonate particles (SB), aluminum trioxide particle abrasion (AT), and diamond bur (DB). Fresh resin composite was bonded to the treated surfaces with one of two bonding agents (Prime&Bond NT, Dentsply/Caulk, Milford, DE, USA; Clearfil SE Bond, Kuraray Co./J., Morita, Japan). The effect of each surface treatment on the bond strength was determined by a shear bond test. Data were analyzed by two-way analysis of variance and Tukey's post hoc test (p = 0.05).

Results: Significant differences were found between the groups, for both surface treatment and bonding agent (p < 0.05). For all surface treatments, the shear bond strengths (SBSs) with Clearfil SE were higher than those with Prime&Bond (p < 0.05). The mean SBS values for the surface treatment groups were, from highest to lowest, 19.3 (DB), 18.7 (AT), 17.4 (SB), 15.2 (HF), 9.2 (C), and 8.8 MPa (PA).

Conclusions: Surface treatment with DB or AT was more effective than with the other surface treatments tested for the repair of nano-filled composites. The adhesive used as an intermediate agent is also important in composite repair.

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Surface treatment with a diamond bur plus a proper adhesive agent is a simple, efficient, and cost-effective procedure for enhancing the shear bond strength of a repaired nano-hybrid resin composite.

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INTRODUCTION

Nomposite resins are widely Jused in restorative dentistry and continue to evolve with the development of more wearresistant filler particles, better resin bonding systems, curing refinements, and improved sealing systems.¹ Although the properties of composites have been enhanced, factors such as wear, discoloration, polymerization shrinkage, and microleakage still limit the longevity of composite restorations.^{2,3} Failures of composite restorations can occur in clinical practice, resulting in the need for replacement or repair of the restorations.

Replacement of failed composite restorations is often undesirable, especially if the existing restoration is close to the pulp, is retained by pins, or is large.⁴ Repairing the defective restoration is often preferred, to preserve healthy tooth structure and to reduce cost and chair-side time.⁵

Successful composite resin repair requires an adequate interfacial bond between the old and fresh composite resins.^{5–9} Many surface conditioning methods and adhesion promoters have been proposed to improve the repair strength of composite resins; these include roughening with burs, etching with hydrofluoric or phosphoric acid (PA), and airborne particle abrasion with aluminum oxide, with or without silane coupling agents or resin-based adhesive systems.^{4,7,9}

Many variables such as the curing process, time of bonding after original curing of the substrate, surface preparation, and use of adhesive resins or silanes affect the bond at the repair site.¹⁰ In previous studies, it was suggested that the effect of a surface treatment on bond strength depended on the substrate surface to be repaired.¹¹ In particular, hydrofluoric acid (HF) seemed to have had little effect on repairing microfilled composite resins.6,12 Lucena-Martín et al. reported that the relative efficacy of air abrasion treatments was different on the surfaces of microhybrid and microfilled composites.⁶ Hannig et al. stated that, although air abrasion with sodium bicarbonate

(SB) particles was effective in repairing hybrid composites, the effect was limited in the repair of ormocers and polyacid-modified resin composites.¹³

Nano-filled composite resins with supposedly superior characteristics such as excellent optical properties, ease of handling, and superior polishability have recently been introduced by several manufacturers. The materials incorporate reinforcing spherical particles, 20 and 70 nm in diameter.¹⁴ High flexural strength, low abrasion, and low polymerization shrinkage are attributed to the high nano-filler fraction.¹⁵

The repair properties of nano-filled composites have not been examined in previous studies. Also, there is no consensus within dentistry regarding the best repair protocol, because of inconsistencies in materials and repair methods used in previous studies. The aim of this study was to evaluate the effect of five different surface conditioning methods in combination with two bonding systems on the repair bond strength of an aged nanofilled resin composite.

MATERIALS AND METHODS

Composite Disks

A nano-filled resin composite (Filtek Supreme XT, 3M ESPE, St. Paul, MO, USA) was used for this study. Restorative resin composite disks (N = 180), 6 mm in diameter and 2 mm in thickness, were prepared using Teflon molds. The surface of the composite was covered with a Mylar strip and compressed with a glass slide to obtain a flat surface on the specimen after light curing. The composite was light polymerized using a light-emitting diode device (LED; SmartLite PS, Dentsply/Caulk, Milford, DE, USA) at an intensity of 950 mW/cm² for 20 seconds, through the glass plate at a 90-degree angle to the top surface. During composite disk preparation, the light intensity of the LED was periodically checked, using a dental curing radiometer (HILUX/ Benlioglu Corp., Ankara, Turkey), to ensure that the light output remained within the recommended limits at all times.

Aging Procedure

The prepared specimens were aged in an accelerated aging chamber. The specimens were mounted on a panel that attached to the frame of an accelerated weathering tester (QUV, The Q-Panel Co., Cleveland, OH, USA) and were kept there for 300 hours. In the weathering tester, specimens were exposed to continuous ultraviolet (UV) and visible light, at a temperature of 43.3°C, and with a programmed cycle of 18 minutes of distilled water spray within each 2-hour period.¹⁶⁻¹⁹

After the aging procedure, all specimens were stored in distilled water for 24 hours at room temperature. Thereafter, the specimens were embedded in acrylic resin blocks, leaving the smooth surfaces of the composite disks uncovered for bonding procedures.

Composite Surface Treatment

The specimens were randomly divided into six groups of 30 specimens each, according to the following surface treatments:

- 1. Group 1 (C), control with no surface treatment
- Group 2 (PA), coated with a thin layer of 38% PA (Pulpdent, Watertown, NY, USA) for 60 seconds, rinsed with water for 30 s, and dried with oil-free air
- Group 3 (HF), coated with a thin layer of 9.6% HF (Pulpdent) for 60 seconds, rinsed with water for 2 minutes, and dried with oil-free air
- Group 4 (SB), sandblasted with SB particles for 15 seconds, using an air-abrasive unit (Air-Flow Handy, EMS, Nyon, Switzerland) at 2.2× atmospheric pressure and 10 mm distance

- Group 5 (aluminum trioxide [AT]), sandblasted with 50-μm AI₂O₃ particles for 10 seconds, using a microetcher (Danville Engineering Inc., Danville, CA, USA) at 10 mm distance
- Group 6 (diamond bur [DB]), roughened at high speed with a DB (150 μm; 856/018, Diatech Diamant AG, Hecrbrugg, Switzerland) and water cooled.

Each group was randomly assigned into two subgroups of 15 specimens each for bonding with two adhesive systems: (1) a total-etch adhesive (Prime&Bond NT, Dentsply/Caulk, Milford, DE, USA), and (2) a self-etch adhesive (Clearfil SE Bond, Kuraray Co./J., Morita, Japan).

Both adhesive systems were applied and polymerized on the aged and treated composite surfaces according to the manufacturers' directions. Following this bonding application, a hollow cylindrical mold (internal diameter, 3 mm; height, 4 mm) was placed by hand on the center of the aged composite, and fresh nano-filled composite (Filtek Supreme XT) was condensed into it in two increments. The first increment filled half of the cylinder, and the second increment filled it to the top. Each increment was light polymerized for 20 seconds. The mold was then carefully removed from the specimen, and another exposure for



Figure 1. Schematic illustration of the shear bond strength test setup.

20 seconds was applied to the specimen to ensure adequate polymerization of the material. Excess composite resin was checked visually and, if present, was removed before curing. The bonding procedures were carried out by the same operator. Thereafter, all specimens were stored in distilled water at 37°C for 1 day.

Shear Bond Strength Test

In the shear bond strength (SBS) tests, each specimen was positioned in a universal testing machine (Lloyd Instruments PLC, Hampshire, UK; Figure 1), with the bonded surface of composite– composite parallel to the direction of the force application. A steel knife edge was placed as close as possible to the bonded surface of composite–composite. The SBS test was performed at a crosshead speed of 1 mm/min (Figure 1). The results of the SBS test were recorded in Newtons and were converted to Megapascals (MPa).

Scanning Electron Microscope Analysis

One sample from each test group was examined under a scanning electron microscope (SEM) to evaluate the effects of the different surface preparation methods on the aged composite surface. The specimens were stored for 2 days in absolute alcohol, air dried for 2 hours, mounted on SEM stubs so that the area of interest could be seen, sputter coated with 10-nm gold particles using a Polaron Sc500 sputter-coating device (VG Microtech Inc., Sussex, England), and observed under a SEM (JSM-5600, JEOL Ltd., Tokyo, Japan) at an operating voltage of 10 kV. Specimens were observed at a 90-degree angle and 23 mm working distance. Photomicrographs were taken at ×500 magnification for visual inspection.

Statistical Analysis

Two-way analysis of variance (ANOVA) was used to examine the effects of surface treatments and bonding agents on the SBS of the repaired composite. The Tukey HSD test was used for post hoc comparisons of the groups. The results were evaluated with a 95% confidence interval. The statistical significance level was p < 0.05.

RESULTS

SBS Comparisons

The mean SBS and standard deviation values for the surface treatment procedures with each of the two bonding agents are shown in Table 1. The Tukey HSD test results of the surface treatment groups are shown in Table 2. Twoway ANOVA revealed significant differences between the groups for both surface treatment and bonding agent (p < 0.05).

There was no significant difference in SBS between the control and PA groups (p > 0.05), which both had statistically lower SBS values than the HF, SB, AT, and DB groups

SURFACE TREATMENTS IN COMBINATION WITH BONDING AGENTS.						
Groups	Prime&Bond NT Mean ± SD (MPa)	Clearfil SE Bond Mean ± SD (MPa)	Difference			
Control	8.1 ± 1.9	11.0 ± 3.2	p = 0.018*			
Phosphoric acid	7.0 ± 1.6	10.6 ± 2.2	p = 0.000*			
Hydrofluoric acid	13.5 ± 5.8	17.0 ± 4.2	$p = 0.032^*$			
Sodium bicarbonate particle abrasion	14.9 ± 4.9	19.8 ± 3.2	<i>p</i> = 0.011*			
Aluminum trioxide particle abrasion	17.8 ± 3.5	19.5 ± 2.7	<i>p</i> = 0.041*			
Diamond bur	15.9 ± 4.9	22.8 ± 4.7	<i>p</i> = 0.003*			
MPa - Meganascal: SD - standard deviation						

MPa = Megapascal; SD = standard deviation. * $p \le 0.05$.

TABLE 2. THE TUKEY HSD RESULTS C GROUPS.	OF THE	SURFACE	TREATMENT	
Groups	N	Subset 1	2	3
Phosphoric acid	30	88.286		
Control	30	92.319		
Hydrofluoric acid	30		152.227	
Sodium bicarbonate particle abrasion	30		173.895	173.895
Aluminum trioxide particle abrasion	30			186.455
Diamond bur	30			193.395
Significance		.999	.406	.527

(p < 0.05). There was no significant difference in SBS between the two abrasive surface treatments (p > 0.05). The mean SBS values of the DB and AT groups were similar to that of the SB group (p > 0.05)but significantly higher than those of the control, PA, and HF groups (p < 0.05). The mean SBS values for the surface treatment groups (Table 2) were, from highest to lowest, 19.3 (DB), 18.7 (AT), 17.4 (SB), 15.2 (HF), 9.2 (C), and 8.8 MPa (PA).

For all surface treatments, the mean SBS values of the Clearfil SE groups were statistically significantly higher than those of the Prime&Bond groups (p < 0.05).

SEM Analysis

Figure 2 shows SEM photomicrographs of the composite surfaces treated with the various surface preparation techniques. As determined from the SEM photomicrographs, the DB gave a rougher surface and more area for micromechanical retention compared with the other treatments. Both the control and PA-etched samples have relatively smooth surfaces. The particle abrasion-treated groups (SB or AT particles) exhibited rougher surfaces than the acid-treated groups (PA or HF).

DISCUSSION

Clinically, the bonding between two composite layers is achieved in the presence of an oxygeninhibited layer of unpolymerized resin.²⁰ However, aged restorations do not contain an unpolymerized surface layer.²¹ The unreactive methacrylate groups, which allow for adhesion of intermediate adhesive agents, are reduced with time, thereby reducing adhesion relative to that of a fresh composite.²² Thus, the age of the restoration is an important factor in composite repairs.^{22,23} In vitro studies simulating the aging process of composites have used methods such as thermocycling and storage in aqueous media or citric acid to age composites.^{22,24} Additionally, accelerated aging processes have been used to simulate aging in the dental literature.¹⁶⁻¹⁹ In an accelerated aging process, composite samples are exposed to continuous UV and visible light, and distilled water, which may change the physical properties of composites. According to the manufacturer of the weathering instrument used in



Figure 2. Scanning electron microscope photomicrographs of composite surfaces after the application of various surface preparation methods at ×500: A, control (no surface treatment); B, phosphoric acid; C, hydrofluoric acid; D, sodium bicarbonate particle abrasion; E, aluminum trioxide particle abrasion; and F, diamond bur.

our study, 300 hours of aging is equivalent to 1 year of clinical service.^{18,25} In the present study, an accelerated aging process was used to provide a more realistic simulation for the repair of older composite restorations. However, there is no consensus as to which aging regimen best simulates oral conditions.²⁶

The SBSs of different composite resins after repairs have been tested in previous studies. Some used composite resins of the same type as their aged and repaired composite,^{26,27} whereas other studies used dissimilar composites for repairing aged composite.⁴ Shahdad and Kennedy²⁷ reported that using identical resin matrix chemistry to repair a composite resin did not produce significantly greater bond strengths than those produced using different matrix chemistry. Moreover, it may not always be possible to clinically determine the composition or brand of the old composite. Furthermore, when an adhesive resin is used as an intermediate bonding agent, the matrix chemistry of the adhesive resin may be more important than the matrix chemistry of the fresh composite resin. However, in the present study, the same type of composite resin was used in order to

eliminate any effect of different composite types in repairing old composites.

The modification of the composite surface texture by chemical and mechanical methods has been performed in attempts to promote composite-to-composite physical interlocking.^{9,28} Two chemical (hydrofluoric and PA) and three mechanical methods (DB, aluminum oxide, SB) were used to modify the composite surfaces in this study.

Surface roughness is a common property known to improve the general adhesion potential of a material, by promoting micromechanical retention between different components. Söderholm and Roberts²³ claimed that surface abrasion was the single most important factor in composite repair. However, several composite repair studies have reported that the grinding of the composite surface decreased the tensile bond strength, as a consequence of filler exposure. Among the surface treatments tested in the present study. the abrasive treatments (DB, AT, SB) produced higher SBSs than the chemical treatments (HF, PA) for the repair of nano-filled composites, although the abrasive SB treatment produced SBSs similar to those of HF (Table 2). However, the effect of a surface treatment may not be the same for all composite types owing to the different matrix structures or inorganic fillers in composites.^{6,11-13}

SB and AT particle abrasion cause microretentive surface features.⁴ The use of a DB for surface roughening may create more macroretentive features, along with microretention, and, thus, would differentially expose more filler particles than an air abrasion method.²⁹ DBs and abrasive systems with different abrasive particles are likely to generate differences in smearing and matrix cracking, and as a result, the SBS of the repaired composite may be affected. It has been reported that PA applied to the surface does not increase or reduce repair bond strength.^{9,12,22} In a previous study, PA did not alter the microscopically observed composite surface characteristics.³⁰ Nevertheless, decomposition of inorganic filler particles can occur after immersion of a composite in acidic medium.³¹ Although this decomposition may impair adhesion between composite lavers, no difference has been observed between the use of adhesive alone and the use of acid followed by adhesive.³⁰ In the present study, treatment with 38% PA slightly, but not significantly, changed the SBS. These results are consistent with the findings of other studies.13,22,29 However, etching the surface of the tooth with PA is necessary in resin restorations when bonding to enamel and dentine. Thus, PA is used in repair procedures, whether or not surface roughness is affected.

HF acts by dissolving the glass particles of the filling, leaving gaps or pores that allow micromechanical retention by the bonding agent⁹ (Figure 2C). In the present study, bond strengths were increased with HF treatment, which gave SBSs similar to those obtained with SB particle abrasion. HF etching is an effective surface treatment for bonding, but the risk for soft tissue burns necessitates extreme care during intraoral application. Furthermore, the effect of HF varies according to the composite to which it is applied. Its effectiveness has been shown to be related to the percentage, size, and type of the inorganic filling.^{6,12} Thus, HF is not recommended as a routine treatment for composite repair, especially when the exact composition of the old composite is unknown.⁴

Although micromechanical interlocking is the basis of the composite repair process,^{13,29} the application of a bonding resin as an intermediate agent is advisable to enhance substrate wetting.^{4,27} In a previous study, it was claimed that surface roughness had more influence on the repair bond strength than did the choice of a bonding agent.²¹ In contrast, Brosh et al.4 explained that unfilled bis-GMA (Bisphenol A-Glycidyl Methacrylate) resin (enamel bond) was the most effective agent for enhancing the SBS of repaired composite specimens, regardless of the surface texture created by the surface treatment. The present study demonstrated statistically significant differences in repair bond strength among the combinations of surface treatments and adhesive agents used, suggesting a synergistic effect between mechanical surface treatments and dentine adhesives.

Surface treatment effects may be masked by the use of a bonding

agent, and those effects might have been better evaluated if negative control groups (without bonding agent) had been added to the study. However, the application of an adhesive resin is clinically mandatory, and repair processes often include both enamel and dentine together with old composite. For this reason, we did not include such negative control groups in the present study.

There is little information regarding the effects of different bonding systems on the repair procedure. Three possible mechanisms accounting for the effects of intermediary resin materials are chemical bond formation to the matrix, chemical bond formation to the exposed filler particles, and micromechanical retention caused by penetration of the monomer components into micro-irregularities in the matrix.²⁶ In the present study, two bonding agents were used as intermediate agents, in order to enhance substrate wetting and produce an unpolymerized layer at the surface of the abraded composite.

Investigations evaluating the influence of different commercially available adhesive systems for composite repair have shown variations in bond strength depending on the adhesive type.³² Previous studies have claimed that the repair bond strength is better with filled adhesive resins than with unfilled adhesives.33,34 In contrast, in the present study, the SBS was higher with Clearfil SE Bond, an unfilled adhesive, than with Prime&Bond NT, a filled adhesive. The viscosity of Clearfil SE is considerably greater than that of Prime&Bond NT, giving Clearfil SE a greater capacity for wetting the surface and penetrating the organic phase of the composite. This result was expected, as these applications contain different solvents in their chemical compositions.

Prime&Bond NT is applied passively as single coat on the treated surface, whereas Clearfil SE is applied actively with a light brushing motion for about 20 seconds. This difference in application techniques may allow the solvent and adhesive of Clearfil SE to better penetrate the surface to be repaired. Clearfil SE also creates a thick adhesive layer on the repaired composite surface; this thick adhesive layer acts as an elastic layer between the old and new composite, improving interfacial quality and strength. In contrast to the Clearfil SE self-etch adhesive, some of the newer self-etching primers and self-etching bonding systems are applied to the repair or tooth surface in one step for a short time. Not all self-etching systems may work well with all composites; more studies are necessary.

The matrix structure of an intermediate agent may be important for bonding to aged composite matrix and may differentially affect bond strength. Dentine bonding agents are based on chlorophosphate esters of bis-GMA, with a surfactant and solvent added. The polar nature of the phosphate groups may contribute to bonding with the inorganic filler component of composites.^{7,27} Clearfil SE is a bis-GMA-based adhesive, and Prime&Bond NT is based on the adhesive UDMA (urethane dimethacrylate). Filtek Supreme XT includes both UDMA and bis-GMA adhesives.

The bond strength necessary for a clinically satisfactory composite repair has not been assessed in vivo. However, it has been reported that the bond strength should be at least 18 to 20 MPa to clinically provide sufficient adhesion to repaired specimens.^{7,13,28} On that basis, the results of the present study suggest that none of the surface treatment methods combined with Prime&Bond NT produced sufficient repair bond strength, whereas the bond strengths produced by the abrasive methods combined with Clearfil SE Bond should be clinically adequate. However, there are many problems with interpreting the results of bond strength studies, and it is often difficult to compare

study results because different methods of testing are frequently employed.³⁵

It was observed by SEM that abrasive treatment of the surface destroys the surface matrix of the composite and creates superficial grooves, pits, and recesses. Mechanical methods of roughening proved more effective than chemical methods (Figure 2A–F). The differences in repair surface topography among the treatments indicated that surface roughness may affect the SBS.

CONCLUSIONS

The findings of the present study strongly support the importance of surface abrasion and micromechanical retention in composite-tocomposite repairs. For the repair of nano-filled composites, DB and AT achieved more effective surface preparation than the other surface treatments tested. As an intermediate adhesive, Clearfil SE Bond resulted in higher bond strengths than Prime&Bond NT.

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REFERENCES

- Bayne SC, Heymann HO, Swift EJ Jr. Update on dental composite restorations. J Am Dent Assoc 1994;125:687–701.
- Gordan VV, Mjör IA, Blum IR, Wilson N. Teaching students the repair of resinbased composite restorations: a survey of North American dental schools. J Am Dent Assoc 2003;134:317–23.
- Mjör IA, Moorhead JE, Dahl JE. Selection of restorative materials in permanent teeth in general dental practice. Acta Odontol Scand 1999;57:257–62.
- 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;77:122–6.
- Blum IR, Schriever A, Heidemann D, et al. The repair of direct composite restorations: an international survey of the teaching of operative techniques and materials. Eur J Dent Educ 2003;7:41–8.
- 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;86:481–8.
- Puckett AD, Holder R, O'Hara JW. Strength of posterior composite repairs using different composite/bonding agent combinations. Oper Dent 1991;16:136– 40.
- Söderholm KJ. Flexure strength of repaired dental composites. Scand J Dent Res 1986;94:364–9.
- Swift EJ Jr, LeValley BD, Boyer DB. Evaluation of new methods for composite repair. Dent Mater 1992;8:362–5.
- Latta MA, Barkmeier WW. Bond strength of a resin cement to a cured composite inlay material. J Prosthet Dent 1994;72:189–93.
- Denehy G, Bouschlicher M, Vargas M. Intraoral repair of cosmetic restorations. Dent Clin North Am 1998;42:719–37.
- Swift EJ Jr, Cloe BC, Boyer DB. Effect of a silane coupling agent on composite repair strengths. Am J Dent 1994;7:200–2.

- Hannig C, Laubach S, Hahn P, Attin T. Shear bond strength of repaired adhesive filling materials using different repair procedures. J Adhes Dent 2006;8:35–40.
- Ure D, Harris J. Nanotechnology in dentistry: reduction to practice. Dent Update 2003;30:10–5.
- Lee YK, Lim BS, Rhee SH, et al. Changes of optical properties of dental nano-filled resin composites after curing and thermocycling. J Biomed Mater Res B Appl Biomater 2004;71:16–21.
- Ramoglu SI, Usumez S, Buyukyilmaz T. Accelerated aging effects on surface hardness and roughness of lingual retainer adhesives. Angle Orthod 2008;78:140–4.
- Anil N, Hekimoglu C, Büyükbas N, Ercan MT. Microleakage study of various soft denture liners by autoradiography: effect of accelerated aging. J Prosthet Dent 2000;84:394–9.
- Anil N, Hekimoglu C, Sahin S. Color stability of heat-polymerized and autopolymerized soft denture liners. J Prosthet Dent 1999;81:481–4.
- Dootz ER, Koran A, Craig RG. Physical property comparison of 11 soft denture lining materials as a function of accelerated aging. J Prosthet Dent 1993;69:114–9.
- Li J. Effects of surface properties on bond strength between layers of newly cured dental composites. J Oral Rehabil 1997;24:358–60.
- Kupiec KA, Barkmeier WW. Laboratory evaluation of surface treatments for composite repair. Oper Dent 1996;21:59–62.
- 22. Ozcan M, Barbosa SH, Melo RM, et al. Effect of surface conditioning methods on the microtensile bond strength of resin composite to composite after aging conditions. Dent Mater 2007;23:1276–82.
- 23. Söderholm KJ, Roberts MJ. Variables influencing the repair strength of dental composites. Scand J Dent Res 1991;99:173–80.
- Yap AU, Sau CW, Lye KW. Effects of aging on repair bond strengths of a polyacid-modified composite resin. Oper Dent 1999;24:371–6.

- Powers JM, Dennison JB, Koran A. Color stability of restorative resins under accelerated aging. J Dent Res 1978;57:964– 70.
- Tezvergil A, Lassila LV, Vallittu PK. Composite-composite repair bond strength: effect of different adhesion primers. J Dent 2003;31:521–5.
- 27. Shahdad SA, Kennedy JG. Bond strength of repaired anterior composite resins: an in vitro study. J Dent 1998;26: 685–94.
- Turner CW, Meiers JC. Repair of an aged, contaminated indirect composite resin with a direct, visible-light-cured composite resin. Oper Dent 1993;18:187–94.
- 29. Bonstein T, Garlapo D, Donarummo J Jr, Bush PJ. Evaluation of varied repair

protocols applied to aged composite resin. J Adhes Dent 2005;7:41-9.

- Cesar PF, Meyer Faara PM, Miwa Caldart R, et al. Tensile bond strength of composite repairs on Artglass using different surface treatments. Am J Dent 2001;14:373–7.
- Kula K, Nelson S, Kula T, Thompson V. In vitro effect of acidulated phosphate fluoride gel on the surface of composites with different filler particles. J Prosthet Dent 1986;56:161–9.
- 32. Dias WR, Ritter AV, Swift Jr EJ. Repairability of a packable resin-based composite using different adhesives. Am J Dent 2003;16:181–5.
- Teixeira EC, Bayne SC, Thompson JY, et al. Shear bond strength of self-etching bonding systems in combination with

various composites used for repairing aged composites. J Adhes Dent 2005;7:159-64.

- Perdigão J, Swift EJ, Lopes GC. Effects of repeated use on bond strengths of onebottle adhesives. Quintessence Int 1999;30:819–23.
- Versluis A, Tantbitojn D, Douglas WH. Why do shear bond tests pull out dentine? J Dent Res 1997;76: 1298–307.

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