Comparative approach to analyse the effects of different surface treatments on CAD/CAM resin nanoceramics–resin composite repair bond strength

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Abstract

Limited data are available on the repair bond strength between computer-aided design and manufacturing (CAD/CAM) resin nanoceramics and composite repair materials. Therefore, the purpose of this study was to test the influence of several different surface treatment modalities, intermediate agents and phosphoric acid on the shear bond strength (SBS) of repair composites with water-aged CAD/CAM resin nanoceramics. Three pretreatment and four conditioning methods comprised 12 different groups. A universal testing machine was used to test the SBS. Specimens were examined with a stereomicroscope and scanning electron microscope to determine the fracture mode. The results showed that a combination of the pretreatment and conditioning methods significantly enhanced the SBS of the resin nanoceramic (p<0.001; p < 0.01), while etching with phosphoric acid did not affect the SBS (p=0.841; p > 0.05). This study showed that surface pretreatment in combination with a conditioning method should be used in the repair of CAD/CAM nanoceramics. The highest SBS values were achieved by grinding the surface with a diamond bur followed by silane and adhesive application, whereas the lowest values were obtained in the non-conditioned non-pretreated group.

Introduction

Resin composites were introduced into the field of dentistry many years ago. A successful resin-based composite material in modern dentistry is required to have certain functional properties, such as high strength, good fracture resistance, a low polymerization shrinkage and a low fatigue and degradation level. The composite materials should be biocompatible, preserve tooth integrity, allow for proper colour matching and polishability; on the other hand they should not cause postoperative hypersensitivity [1]. Indirect resin-based composite restorations have been used as an alternative to direct restorations to avoid polymerization shrinkage and to improve the mechanical and physical properties of final restorations [2]. Laboratory-processed composites have shown reduced deficiencies, increased degrees of conversion and higher wear resistance. Further advantages include minimizing the challenges that clinicians encounter while performing direct composite restorations, such as isolation difficulties and the challenge of achieving proper interproximal contacts and building lifelike restorations. With computer-aided design and manufacturing (CAD/CAM) technology, indirect composite restorations have gained a new dimension. CAD/CAM technology enables dentists to fabricate restorations with a level of quality comparable to their counterparts fabricated with conventional techniques in a short-time. Recently, a new millable CAD/CAM restorative material (LavaTM Ultimate CAD/CAM Restorative, Technical Product Profile, 3M ESPE, 2011), composed of silica (20 nm) and zirconia (4–11 nm) nanomers embedded in a highly cured resin matrix, was introduced to the field of dentistry. This material is called Resin Nano Ceramic (RNC). RNC has been shown to be resistant to human masticatory forces, even with a minimum thickness of only 0.5 mm [3,4]. Posterior crowns made of RNC showed a higher fatigue resistance than those made of feldspathic glass ceramic and produced less wear on the antagonist composite resin sphere [5].

Along with the superior physical and mechanical properties, the repairability of a restorative dental material is also crucial for minimally invasive dentistry. Importantly, repairing is no longer considered to be substandard patchwork dentistry; instead, the teaching of repairing restorations has been introduced into the classroom in universities [6]. In vitro studies have found that repaired restorations have even higher survival rates than replaced restorations [7]. Since the 1970s, research...
has started to include the possibility of repairing resin-based composites. The determination of whether to replace or to repair a failed restoration depends on numerous factors, such as the type of failure, the material properties and the cost-effectiveness [6,8].

The oxygen-inhibited layer of unpolymerized resin plays a crucial role in the long-term bonding of two composite layers. Because CAD/CAM composites are polymerized under standardized high pressure and temperature, they do not contain the unpolymerized surface layer, similar to aged resin-based composites [9]. Furthermore, due to its increased water adsorption and saturation, the repair strength of aged resin-based composites has been reported to be lower than the cohesive strength of the fresh composite [10].

The composite can be repaired with using an intermediate unfilled resin material to provide chemical bonding to the exposed filler particles and the resin matrix, with micromechanical retention via the penetration of the monomers into the resin matrix [11]. Mechanical retention can be provided with some surface treatment modalities, such as roughening the surface with a coarse diamond bur [11–19], a rotary cutting instrument [20–24], a sandblasting or air-abrasion system with aluminium oxide powder [11,25], or phosphoric [26] or hydrofluoric acid [18].

To simulate the aging process of composite resins, the citric acid immersion technique [27], water storage [12,28] and thermocycling [29,30] have been used in various studies. The effects of these various in vitro aging methods produce different results, and in fact there is no in vitro regimen that exactly replicates the conditions of the oral cavity.

Although CAD/CAM resin-based materials have been reported as resistant to functional masticatory forces, under heavy loads due to trauma or parafunctional habits, these materials may fracture and need to be repaired intraorally. Surface treatment on the fractured surface of composite resin materials must be performed to obtain high bond strength between the materials. Although there is a great deal of information about the effect of several treatment methods on the bonding strength of composite restorations [18,20,27,31–42], very limited data are available on the use of surface treatment of CAD/CAM resin-based materials [26,37,43–46] to enhance their repair bond strength.

The aim of this study was to test the influence of the selected different surface treatment modalities in combination with intermediate agents on the shear bond strength (SBS) of resin-based composites to water aged CAD/CAM RNC. The null hypothesis of this study was that the (i) different surface treatments, (ii) the presence of phosphoric acid and (iii) the conditioning methods used would not affect the resulting CAD/CAM RNC-resin composite bond strength.

Materials and methods

Experimental design

Two hundred and forty slices (3 mm thick \times 5 mm wide \times 5 mm long) of RNC specimens (LAVA Ultimate 3M ESPE, Germany) were cut from CAD/CAM blocks under water cooling using a fully automatic cutting machine (Isomet, Buehler, USA; rotational speed 0–300 rpm). All specimen surfaces were polished sequentially with silicon carbide paper (grit 600, 800, 1000; English Abrasives &Chemicals Ltd., London, UK) on a polishing machine (Phoenix Beta, Buehler, IL, USA) under water cooling to achieve standardized surface roughness.

Thereafter, the specimens were water aged for 10,000 thermal cycles between 5 and 55 °C with a rest time of 20 s in each bath (Thermocycler, Salubris-technica, Turkey). The samples were then embedded in a metal ring holder (13 mm in height and 15 mm in diameter) with a self-cured acrylic resin. The 240 specimens were then randomly divided into three test groups (n = 80) according to the following surface treatments: (i) pretreatment with Cojet, (ii) roughening with a coarse diamond bur and (iii) no pretreatment. One additional specimen for each group was produced to assess the surface micro-morphology and to perform scanning electron microscopy (SEM; EVO 40, Carl ZEISS, Germany).

After pretreatment, the bonding surfaces of half of each group (n = 40) were etched with phosphoric acid (3M ESPE Scotchbond-Etchant) for 30 s. Then, all of the specimens were rinsed with distilled water for 60 s and dried with oil-free compressed air. Both etched and non-etched groups were then divided into four subgroups of 10 specimens each and subjected to different conditioning methods, as follows:

1. Adper Scotchbond multipurpose adhesive (3M ESPE, St. Paul, MN, USA);
2. Scotchbond universal (3M ESPE);
3. Ultradent silane (Ultradent, USA) + Adper Scotchbond multipurpose adhesive (3M ESPE, St. Paul, MN, USA);
4. No conditioning, serving as the control group.

Directions for applications and compositions of all tested materials are given in Tables 1 and 2. Before conditioning of the specimens, adhesive tapes with 3.0 mm-diameter circular holes on the surface were placed on the specimen to standardize the bonding area. Subsequently, the repair composite (Filtek Z250, 3M ESPE) was
applied using a transparent rubber ring mold (with an inner diameter of 3 mm and a height of 4 mm) in approx. 2 mm increments that were separately polymerized for 20 s. The adhesive tapes and the cylinders were carefully removed. All specimens were stored in distilled water at 37°C for 24 h for further polymerization.

A universal testing machine (Model 3345; Instron, Norwood, MA, USA), with a 1 mm/min crosshead speed, was used to test the SBS (Figure 1). A stereomicroscope (Leica MZ16FA, Wetzlar, Germany) at £40 magnification was used to determine the fracture pattern. Failures were classified into the following types: (i) adhesive failure (with no repair composite on the polished specimen surface), (ii) cohesive failure (failure within the CAD/CAM material or the repair composite), (iii) a combination of both types of failure, or (iv) prefailure (failure before the SBS test).

Additional specimens were gold-coated using an ion-sputtering device (SCD 005, sputter coater, Baltec) and then evaluated under SEM to assess the surface texture to observe the treatment methods.

### Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics 22 software (IBM SPSS, Turkey). The normality of the data distribution was tested using the Shapiro–Wilk test. Three-way analysis of variance (ANOVA) and one-way ANOVA were used to determine the effect of surface pretreatment, conditioning method and acid etching on the SBS. Tamhane’s T2 test was used to determine which groups differed. Student’s t-test was used to compare the parameters between the two tested groups. The significance level was set at p ≤ 0.05.

### Results and discussion

This study aimed at assessing the effects of combinations of different surface pretreatment and conditioning methods on the repair bond strength of CAD/CAM nanoceramics with composite resins. The SBS test was used to evaluate the repair potential of the water-aged nanoceramics.

### Table 1. Manufacturer and composition of the materials used in this study.

| Product name | Manufacturer | Composition |
|--------------|--------------|-------------|
| CAD/CAM RNC LAVA ultimate | 3M ESPE, Seefeld, Germany | Polymer with approx. 80 wt% inorganic filler |
| Pretreatment method Scotchbond universal etchant phosphoric acid | 3M ESPE, Seefeld, Germany | Water, phosphoric acid, silica, polyethylene glycol, aluminum oxidized |
| Scotchbond universal | 3M ESPE, Seefeld, Germany | Silicatized sand (30 μm) |
| Conditioning method Scotchbond universal | 3M ESPE, Seefeld, Germany | MDP phosphate monomer, DM, HEMA, Vitrebond copolymer, filler, ethanol, water, silane |
| Adper scotchbond multipurpose adhesive | 3M ESPE, St Paul, MN, USA | BisGMA (60–70 wt%), HEMA (30–40 wt%) |
| Ultradent silane | Ultradent products, South Jordan, UT, USA | Methacryloxy propyl trimethoxy silane 15%, isopropyl alcohol 92% |
| Resin composite Filttek Z250 | 3M ESPE, St Paul, MN, USA | Bisphenol A diglycidylmethacrylate (Bis-GMA), urethane dimethacrylate (UDMA) and ethoxylated bisphenol A glycol dimethacrylate (Bis-EMA) resins |
The three-way ANOVA results (Table 3) showed that the surface pre-treatments and conditioning methods had a significant influence on the mean SBS values ($p < 0.01$). Additionally, the interaction between these two variables significantly affected the SBS ($p < 0.01$). Among the conditioned groups, no significant differences were found. For the diamond bur roughened nonacid-treated group, non-conditioning resulted in lower SBS values than conditioning ($p < 0.001$). Among the conditioned groups, no significant differences were found. For the diamond bur roughened nonacid-treated group, non-conditioning resulted in lower SBS values than conditioning ($p < 0.001$). No differences ($p > 0.05$) were observed between the influence of different conditioning methods on SBS.

The conditioned-nonpretreated groups, regardless of the acid-etching status, showed significantly higher SBS values than the non-conditioned-non pretreated group. The conditioning methods for the nonpretreated group also showed no differences in the impact on SBS ($p > 0.05$). Figure 2 shows SEM photomicrographs of the CAD/CAM resin nanoceramic surfaces treated with the surface pretreatment modalities and phosphoric acid. Although the cojet treatment produced a relatively rough surface, the diamond application created the roughest and the most irregular surface. Phosphoric acid etching did not produce clear changes in the surface texture of the specimens compared with the untreated samples. The number of failure modes for all tested groups is presented in Table 5.

In previous studies, the composite–composite repair strength is evaluated utilizing an SBS test for both fresh groups had no impact from acid etching on their SBS results ($p > 0.05$).

Three-way ANOVA found an influence of the conditioning method on the mean SBS values. Tamhane’s T2 test revealed that the nonconditioned group showed significantly lower SBS values than the conditioned groups ($p < 0.01$). The use of ScotchBond universal and Ultradent silane application followed by Multipurpose adhesive and the use of Multipurpose adhesive alone did not have significantly different SBS values ($p > 0.05$).

Table 3. Influence of each treatment method on the SBS values.

|                | SBS          | F    | p       |
|----------------|--------------|------|---------|
|                |              |      |         |
| Surface pretreatment | 64.673       | 0.001** |         |
| Conditioning    | 47.790       | 0.001** |         |
| Acid etching    | 0.041        | 0.841 |         |
| Surface pretreatment, acid etching | 0.645        | 0.526 |         |
| Conditioning, acid etching | 1.651        | 0.179 |         |
| Surface pretreatment, conditioning | 4.186        | 0.001** |         |
| Surface pretreatment, conditioning, acid etching | 0.418        | 0.867 |         |

Note: Three-way ANOVA, ** $p < 0.01$.

Table 4. SBS values of the tested groups.

| Surface pretreatment | Conditioning | Acid Ort ± SS | Non-acid Ort ± SS | $^2p$ |
|----------------------|--------------|---------------|-------------------|------|
| Cojet                | Silane + Adper adhesive | 16.44 ± 8.0 | 17.33 ± 9.47 | 0.822 |
|                      | Adper adhesive | 15.49 ± 14.64 | 17.64 ± 10.37 | 0.709 |
|                      | Scotchbond universal | 19.26 ± 8.13 | 20.5 ± 8.29 | 0.740 |
|                      | No conditioning | 6.15 ± 1.91 | 3.93 ± 1.96 | 0.019* |
|                      | $^1p$ | 0.020* | 0.001** |        |
| Diamond              | Silane + Adper adhesive | 31.6 ± 18.28 | 24.07 ± 12.18 | 0.293 |
|                      | Adper adhesive | 21.54 ± 6.68 | 24.34 ± 12.45 | 0.538 |
|                      | Scotchbond universal | 31.26 ± 9.24 | 30.27 ± 3.73 | 0.758 |
|                      | No conditioning | 7.82 ± 3.05 | 6.04 ± 2.38 | 0.163 |
|                      | $^1p$ | 0.001** | 0.001** |        |
| No pretreatment      | Silane + Adper adhesive | 8.71 ± 4.08 | 7.2 ± 2.37 | 0.326 |
|                      | Adper adhesive | 9.88 ± 5.49 | 15.4 ± 4.93 | 0.029* |
|                      | Scotchbond universal | 9.87 ± 5.12 | 9.04 ± 6.37 | 0.753 |
|                      | No conditioning | 0.60 ± 0.68 | 0.34 ± 0.32 | 0.289 |
|                      | $^1p$ | 0.001** | 0.001** |        |

$^a$ Mean values with standard deviation (±SD); $^1$ One-way ANOVA; $^2$ Student’s t test; $^{*}p < 0.05$; $^{**}p < 0.01$. 
and aged samples [20]. Although SBS evaluation has been reported to be a less reliable mechanical test than the micro-tensile bond strength test due to leading to non-uniform distribution of the stresses at the adhesive area [47,48], the forces applied to the repair area are predominantly in the shear mode. Moreover, it should be noted that there is no consensus on which method is preferable [32,49]. The SBS test is simple, allowing for the efficient screening of adhesive systems [50].

Based on the obtained data, the first null hypothesis (that the application of the different surface pretreatments would not affect the CAD/CAM RNC-resin composite bond strength) was rejected. The mechanical roughening of the substrate surface was found to be an important factor in the repair bond strength [14,33]. In the present study, the mechanical roughening of the composite specimens with the diamond bur and cojet treatment resulted in increased repair bond strength values without conditioning methods. In combination with the conditioning methods, the diamond bur roughening showed significantly higher SBS values than those of the cojet application. This finding corroborates those of Yeşilyurt et al. [18] but contradicts those of Loomans et al. [34], who reported no differences between the diamond stone grinding and silica coating. An increase in the repair bond strength after the application of the diamond bur and cojet might be due to an increase in the surface roughness of the specimens and an increase in the bonded surface area, which was confirmed by SEM micrographs. Surface roughening has been reported to increase the surface energy and adhesive wettability [35,36]. Depending on these findings, grinding with a diamond bur, which is a quick and easy way of roughening, can be recommended as a pretreatment method for repair of CAD/CAM RNC.

By using a tribochemical cojet system (3M ESPE, Seefeld, Germany), the surface of the substrate was partially coated with silica-coated alumina particles to create a more retentive surface area. Further silane application is then required to form covalent bonding between the silica-coated layer and the repaired resin composite. However, the silane application did not significantly affect the repair bond strength, regardless of whether it was applied as a separate step or as part of the bonding agent, or after cojet or diamond bur grinding. This finding is consistent with the results of several previous studies [16,37,38] and was corroborated by the finding that the failure mode of the repaired bond between substrates with or without silane showed no differences between the groups tested. Moreover, this finding may reflect the reality that the effect of pretreatment had a greater influence than conditioning on the bond strength. Furthermore, the silica coating and silanization
has been found to create similar repair bond strength as the diamond stone roughening for the CAD/CAM composite block [37]. In a study by Rathke et al. [39], sandblasting with silica-coated particles followed by a silane treatment step was found to produce no advantage over common bonding systems in the repair of microhybride composites [25]. In contrast [20,24,40,41], we found that silica coating in combination with the use of silane treatment resulted in the highest mean repair bond strength of composites when compared with phosphoric acid and adhesive resin application. In addition, the use of silane after the diamond bur roughening has been previously reported to increase the repair bond strength of composites [11]. This contradiction could be attributed to differences in the composition between the repaired composites and the chosen methodology.

The results from our study showed that the additional use of an adhesive system significantly increased the repair bond strength of CAD/CAM composites. Thus, the second null hypothesis of the study was also rejected. However, the efficiency of the tested adhesive systems was not significantly different, and the single universal bond performed better than the other system (Ultradent silane + Adper scotchbond multipurpose adhesive, Adper scotchbond multipurpose adhesive). This slight increase could be due to the contribution of the phosphate monomers in the universal bond. These additional monomers have the potential to bond directly to the OH groups of the zirconia nanomers in the LAVA composites.

Previous studies have reported both positive and negative effects of phosphoric acid on the bond strength of composites. Cesar et al. [28] observed no alterations in the surfaces of indirect composite after phosphoric acid application, and no differences were found in the bond strength between the composite resin layers after the utilization of acid alone or acid in combination with adhesive. Kula et al. [42] reported that the immersion of composites in acidic medium resulted in the decomposition of their inorganic filler particles and may affect their bond strength negatively. In this study, no marked surface topography changes were observed after acid etching in the SEM micrograph; indeed, the acid treatment appeared only to have a cleaning effect [13,14,33,51]. However, the results of the acid application on SBS values varied differently among the tested groups and the adhesive systems assessed. This result was consistent with the findings of Stawarczyk et al. [26]. Differences in the findings may be attributed to the different compositions of the resin composites studied and interactions between the pretreatment and adhesive acid application in each study.

Bond strength of 15 MPa has been reported as a sufficient value of bond strength of CAD/CAM resin ceramic hybrid materials. [44] Consistent with the study by Güngör et al. [44], RNC showed bond strength of > 15 MPa for all of the groups except for nonpretreated and/or non-conditioning groups. These results indicate that, in any case, surface treatment with the conditioning method should be performed before the repair process.

In this study, the specimens were subjected to 10,000 thermal cycles between 5°C and 55°C. Thermocycling generates thermal stresses due to differences between thermal expansion of components of the restorative material. These stresses lead to microcracks in the matrix or failure at the filler–matrix interface [29,30,52]. The degradation of the filler’s silane coating or swelling of the matrix can occur [30,53]. These changes may affect the SBS values of the repaired composite materials. To date, there is no consensus on which in vitro aging method best simulates the oral condition. However, standardized and reproducible stresses are implemented to all specimens by thermocycling [43].

In the present study, the role of the selected surface treatments on the SBS values of CAD/CAM RNC was evaluated. Other surface treatment methods with a large

### Table 5. Failure modes of tested groups.

| Surface pretreatment | Conditioning method | Acid | Non-acid |
|----------------------|---------------------|------|----------|
|                      |                     | C    | Z250     | C     | Lava | M | P | A    | C    | Z250 | C     | Lava | M | P |
| Cojet                | Silane + Adper adhesive | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cojet                | Adper adhesive      | 8   | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cojet                | Scotchbond universal | 6   | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cojet                | No conditioning      | 10  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Diamond bur          | Silane + Adper adhesive | 3   | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Diamond bur          | Adper adhesive      | 8   | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Diamond bur          | Scotchbond universal | 1   | 3 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No-Pretreatment      | Silane + Adper adhesive | 5   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No-Pretreatment      | Adper adhesive      | 9   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No-Pretreatment      | Scotchbond universal | 10  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No-Pretreatment      | No conditioning      | 10  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Note: A, adhesive; C, cohesive; M, mixed; P, prefailure.
number of specimens should be performed on CAD/CAM RNC to provide reliable information for clinicians. Moreover, this study investigated the bond strength between aged nanoceramics and newly added composite resin. However, aging could affect the repaired composite-adherent complex. Further studies are therefore required to investigate the aforementioned limitations.

Conclusions
The results from this study showed that surface pretreatment in combination with a conditioning method should be used in the repair of CAD/CAM RNC. Diamond bur grinding followed by adhesive with silane was found to be a more effective method than silica coating. From the perspective of nanotechnology in dentistry, this study indicates that CAD/CAM RNC with its intraoral repairment capacity gives promise for a successful clinical future.

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References
[1] Ilie N, Hickel R. Resin composite restorative materials. Aust Dent J. 2011;56(Suppl. 1):59–66.
[2] Nandini S. Indirect resin composites. J Conserv Dent. 2010;13(4):184–194.
[3] Johnson AC, Versluis A, Tantbirojn D, et al. Fracture strength of CAD/CAM composite and composite-ceramic occlusal veneers. J Prosthodont Res. 2014;58(2):107–114.
[4] Chen C, Trindade FZ, de Jager N, et al. The fracture resistance of a CAD/CAM resin nano ceramic (RNC) and a CAD ceramic at different thicknesses. Dent Mater. 2014;30(9):954–962.
[5] Carvalho AO, Bruzi G, Giannini M, et al. Fatigue resistance of CAD/CAM complete crowns with a simplified cementation process. J Prostheth Dent. 2014;111(4):310–317.
[6] Hickel R, Brüchner K, Ilie N. Repair of restorations–criteria for decision making and clinical recommendations. Dent Mater. 2013;29(1):28–50.
[7] Gordan VV, Garvan CW, Blaser PK, et al. A long-term evaluation of alternative treatments to replacement of resin-based composite restorations: results of a seven-year study. J Am Dent Assoc. 2009;140(12):1476–1484.
[8] Tyas MJ, Anusavice KJ, Frencken JE, et al. Minimal intervention dentistry–a review. FDI Commission Project 1:97. Int Dent J. 2000;50(1):1–12.
[9] Hori S, Minami H, Minesaki Y, et al. Effect of hydrofluoric acid etching on shear bond strength of an indirect resin composite to an adhesive cement. Dent Mater. 2008;27(4):515–522.
[10] Ilie N, Oberthür M-T. Effect of sonic-activated resin composites on the repair of aged substrates: an in vitro investigation. Clin Oral Investig. 2014;18(6):1605–1612.
[11] Brosh T, Blutstein R, Maurice T, et al. Effect of combinations of surface treatments and bonding agents on the bond strength of repaired composites. J Prostheth Dent. 1997;77:122–126.
[12] Frankenberger R, Krämer N, Ebert J, et al. Fatigue behavior of the resin-resin bond of partially replaced resin-based composite restorations. Am J Dent. 2003;16(1):17–22.
[13] Shahdad SA, Kennedy JG. Bond strength of repaired anterior composite resins: an in vitro study. J Dent. 1998;26(8):685–694.
[14] Bonstein T, Garlapo D, Donarummo J, et al. Evaluation of varied repair protocols applied to aged composite resin. J Adhes Dent. 2005;7(1):41–49.
[15] Fawzy AS, El-Askary FS, Amer MA. Effect of surface treatments on the tensile bond strength of repaired water-aged anterior restorative micro-fine hybrid resin composite. J Dent. 2008;36(12):969–976.
[16] Bouschlicher MR, Reinhardt JW, Vargas MA. Surface treatment techniques for resin composite repair. Am J Dent. 1997;10(6):279–283.
[17] Cavalcanti AN, De Lima AF, Peris AR, et al. Effect of surface treatments and bonding agents on the bond strength of repaired composites. J Esthet Restor Dent. 2007;19(2):90–98; discussion 99.
[18] Yesilyurt C, Kusgoz A, Bayram M, et al. Initial repair bond strength of a nano-filled hybrid resin: effect of surface treatments and bonding agents. J Esthet Restor Dent. 2009;21(4):251–260.
[19] Chiba K, Hosoda H, Fusayama T. The addition of an adhesive composite resin to the same material: bond strength and clinical techniques. J Prostheth Dent. 1989;61(6):669–675.
[20] 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(10):1276–1282.
[21] Baur V, Ilie N. Repair of dental resin-based composites. Clin Oral Investigat. 2013;17(2):601–608.
[22] 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(2):159–164.
[23] Lührs AK, Görmann B, Jacker-Gühr S, et al. Repairability of dental siloranes in vitro. Dent Mater. 2011;27(2):144–149.
[24] Hisamatsu N, Atsuta M, Matsumura H. Effect of silane primers and unfilled resin bonding agents on repair bond strength of a prosthodontic microfilled composite. J Oral Rehabil. 2002;29(7):644–648.
[25] Brendeke J, Ozcan M. Effect of physicochemical aging conditions on the composite-composite repair bond strength. J Adhes Dent. 2007;9(4):399–406.
[26] Stawarczyk B, Krawczuk A, Ilie N. Tensile bond strength of resin composite repair in vitro using different surface preparation conditionings to an aged CAD/CAM resin nanoceramic. Clin Oral Investigat. 2015;19(2):299–308.
Yap AU, Sau CW, Lye KW. Effects of aging on repair bond strengths of a polyacid-modified composite resin. Oper Dent. 1999;24(6):371–376.

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(6):373–377.

Hakimeh S, Vaidyanathan J, Houpt ML, et al. Microleakage of compomer class V restorations: effect of load cycling, thermal cycling, and cavity shape differences. J Prostheth Dent. 2000;83(2):194–203.

Kawano F, Ohguri T, Ichikawa T, et al. Influence of thermal cycles in water on flexural strength of laboratory-processed composite resin. J Oral Rehabil. 2001;28(8):703–707.

Lewis G, Johnson W, Martin W, et al. Shear bond strength of immediately repaired light-cured composite resin restorations. Oper Dent. 2001;23(3):121–127.

Rinastiti M, Özcan M, Siswomihardjo W, et al. Effects of surface conditioning on repair bond strengths of non-aged and aged microhybrid, nanohybrid, and nanofilled composite resins. Clin Oral Investig. 2011;15(5):625–633.

Lucena-Martín C, González-López S, Navajas-Rodríguez de Monelo JM. The effect of various surface treatments and bonding agents on the repaired strength of heat-treated composites. J Prosthet Dent. 2001;86(5):481–488.

Loomans BAC, Cardoso MV, Roeters FJM, et al. Is there one optimal repair technique for all composites? Dent Mater. 2011;27(7):701–709.

Kimyai S, Mohammadi N, Navimipour EJ, et al. Comparison of the effect of three mechanical surface treatments on the repair bond strength of a laboratory composite. Photomed Laser Surg. 2010;28(Suppl. 2):S25–S30.

Cho SD, Rajitrangson P, Matis BA, et al. Effect of Er, Cr: YSGG laser, air abrasion, and silane application on repaired shear bond strength of composites. Oper Dent. 2010;35(3):E1–E9.

Zaghoul H, Elkassas DW, Haridy MF. Effect of incorporation of silane in the bonding agent on the repair potential of machinable esthetic blocks. Eur J Dent. 2014;8 (1):44–52.

Matlinlnna JP, Vallittu PK. Bonding of resin composites to etchable ceramic surfaces – an insight review of the chemical aspects on surface conditioning. J Oral Rehabil. 2007;34(8):622–630.

Rathke A, Tymina Y, Haller B. Effect of different surface treatments on the composite-composite repair bond strength. Clin Oral Investig. 2009;13(3):317–323.

Söderholm KJ, Roberts MJ. Variables influencing the repair strength of dental composites. Scand J Dent Res. 1991;99 (2):173–180.

Swift EJ, Cloe BC, Boyer DB. Effect of a silane coupling agent on composite repair strengths. Am J Dent. 1994;7 (4):200–202.

Kula K, Nelson S, Kula T, et al. In vitro effect of acidulated phosphate fluoride gel on the surface of composites with different filler particles. J Prosthodont. 1986;56(2):161–169.

Bähr N, Keul C, Edelhoff D, et al. Effect of different adhesives combined with two resin composite cements on shear bond strength to polymeric CAD/CAM materials. Dent Mater J. 2013;32(3):492–501.

Güngör MB, Nemli SK, Bal BT, et al. Effect of surface treatments on shear bond strength of resin-composite bonded to CAD/CAM resin-ceramic hybrid materials. J Adv Prosthodont. 2018;6(4):259–266.

Duzyol M, Sagsoz O, Polat Sagsoz N, et al. The effect of surface treatments on the bond strength between CAD/CAM blocks and composite resin. J Prosthet Dent. 2016;25 (6):466–471.

Üstün Ö, Büyükatipoğlu İK, Seçilmiş A. Shear bond strength of repair systems to new CAD/CAM restorative materials. J Prosthodont. Forthcoming. 2017. DOI:10.1111/jopr.12564

Della Bona A, van Noort R. Shear vs. tensile bond strength of resin composite bonded to ceramic. J Dent Res. 1995;74(9):1591–1596.

Versluis A, Tantbirojn D, Douglas WH. Why do shear bond tests pull out dentin? J Dent Res. 1997;76(6):1298–1307.

Della Bona A, Anusavice KJ, Shen C. Microtensile strength of composite bonded to hot-pressed ceramics. J Adhes Dent. 2000;2(4):305–313.

Armstrong S, Geraldeli S, Maia R, et al. Adhesion to tooth structure: a critical review of “micro” bond strength test methods. Dent Mater. 2010;26(2):e50–e62.

Dall’Oca S, Papacchini F, Radovic I, et al. Repair potential of a laboratory-processed nano-hybrid resin composite. J Oral Sci. 2008;50(4):403–412.

Crim GA, García-Godoy F. Microleakage: the effect of storage and cycling duration. J Prosthodont. 1987;57(5):574–576.

Ortgengen U, Andersson F, Elgh U, et al. Influence of pH and storage time on the sorption and solubility behaviour of three composite resin materials. J Dent. 2001;29(1):35–41.