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Microtensile Repair Bond Strength of a Composite After Accelerated Artificial Aging: Effect of the Air Abrasion, Bur, Er:YAG Laser, Two-Step Self-etch Bonding, and Universal Bonding Repair System

Marie Rashidi[1], Simin Berangi[2], Nasim Chiniforush[3], Elham Ahmadi[4], Ladan Ranjbar Omrani[5*]

[1]Department of Restorative Dentistry, Dental School, Kurdistan University of Medical Sciences, Sanandaj, Iran
[2]School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran
[3]Laser Research Center of Dentistry (LRCD), Research Dentistry Institute, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran
[4]Dental Research Center, Research Dentistry Institute, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran
[5]Laser Research Center of Dentistry (LRCD), Dental Research Center, Research Dentistry Institute, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran

***Correspondence to**
Ladan Ranjbar Omrani, DDs, MSc of Restorative Dentistry, Associated Professor, Dental School of Tehran University of Medical Sciences North Amir Abad, Tehran, Iran.
Tel:+989122132110,
Email: ladanomrani@yahoo.com

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Abstract
Introduction: Repair of old composite restorations is a conservative approach. This study sought to compare the effects of two adhesive systems on the bond strength of repaired composites prepared by three different surface treatments: erbium-doped yttrium aluminum garnet (Er:YAG) laser irradiation, air-abrasion, and bur preparation.
Methods: Eight microhybrid (Polofil Supra, VOCO, Germany) composite resin blocks were fabricated. The blocks were aged and assigned to four groups as stated by the surface treatment: (I) air-abrasion (50 µ aluminum oxide particles), (II) diamond bur (fine grit), (III) Er:YAG laser (3 W output power, 300 mJ energy) and (IV) control. After surface treatment, the blocks were acid-etched and salinized. Each group was divided two subgroups, and the Clearfil SE Bond or All-Bond Universal was applied on their surface. Composite resin was bonded to the aged composites. The blocks were cut into eight samples, and the microtensile bond strength (MTBS) was measured.
Results: The maximum MTBS was noted in the air-abrasion (25.1 + 6 MPa) group, followed by the Er:YAG laser (21.2 + 4.7 MPa). The mean MTBS in laser and air-abrasion groups was significantly higher than that in other groups ($P<0.05$). The mean MTBS was not significantly different between the laser and air-abrasion groups ($P>0.05$). Composite resin conditioning by All-Bond Universal in laser and air-abrasion groups yielded significantly higher MTBS than the Clearfil SE Bond ($P<0.05$).
Conclusion: All surface treatments created acceptable bond strength. The surface treatment of the aged composite by the Er:YAG laser or air-abrasion along with the application of silane and All-Bond Universal provide high bond strength.
Keywords: Air abrasion; Composite resins; Tensile strength; Lasers.

Introduction

At present, composite resins are extensively used due to their favorable bonding and esthetic properties and preserving the sound tooth structure.[1-3] Some challenging conditions such as thermal alterations in the oral environment, water sorption by resin compounds, polymerization shrinkage, and pH challenge can affect the resistance and durability of composite restorations and cause the degradation of the composite resin or the bonding agent.[4] Chipping, cracking, and development of secondary caries are the main reasons necessitating restoration replacement.[5,6]

The complete replacement of a defective dental restoration requires further tooth preparation.[7] Also, restoration replacement averagely takes 60% more time than restoration repair.[8] Thus, restoration repair can be a more logical and cost-effective approach.[9,10] In restoration repair, the adequate bond strength of the repaired composite is highly important, which can be provided by macromechanical, micromechanical, or chemical retention.[11,12]

Several studies have assessed the effects of chemical or mechanical surface treatments of the composite on repair bond strength. In general, diamond bur preparation is

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selected by most dentists for the preparation of composite surfaces before restoration repair.[13-15]

Surface roughening by the bur or aluminum oxide particles enhances micromechanical retention between the old composite surface and the bonding agent. This is an acceptable method to enhance repair bond strength.[10]

Laser applications in dentistry are increasing worldwide.[16-18] Due to recent advances in dental lasers, surface treatment with the erbium-doped yttrium aluminum garnet (Er:YAG) laser is currently considered as an alternative to other surface treatments.[19] Laser irradiation can increase the porosities of the aged composite resin and increase the repair bond strength of new to aged composites.[18]

It seems that adhesives have a significant role in the bond strength of repaired composite resins by increasing the wettability of the composite surfaces.[17] Recently, a new generation of adhesives was introduced to the market, known as multi-mode or universal adhesives, which possess active phosphate-containing monomers in addition to the conventional functional monomers.[19]

Investigations into the efficacy of Er:YAG laser irradiation and universal bonding agents for surface treatment in composite restoration repair are limited, and further studies are required in this respect. Thus, this study sought to assess the effects of three surface treatments and two bonding agents on the repair bond strength of an aged microhybrid composite.

Materials and Methods

Eight microhybrid composite resin blocks (A3 Shade; Polofil Supra, VOCO, Germany) were made by a stainless-steel mold (12 × 8 × 2 mm). The mold was located on a glass slab, and a composite was applied in one increment into the mold using a plastic instrument and condensed wholly. The samples were light-cured from a 1-mm distance for 20 seconds using a LED light-curing unit (Woodpecker LED.F, China) with a light intensity of 1000 mW/cm^2 from both sides. After five applications, the light intensity was checked using a radiometer (Optilux Model-100 SDS Kerr, USA). The samples were detached from the mold, and subsequently, the excess composite was eliminated. The surface of the composite blocks was polished with a 600-grit abrasive disc to remove the superficial layer and create a uniform surface. The composite blocks then underwent accelerated aging in the Xenotest Alpha chamber (Heraeus Kulzer, Germany). The blocks were exposed for 150 hours at 55°C and 100% humidity (corresponding to 6 months of aging) to a xenon lamp (5000°K-7000°K and 150 000 Lux). The xenon lamp has a filter that converts its spectral energy distribution to visible light.[20]

After accelerated aging, the blocks were randomly divided into four groups (n = 2):

1. Sandblasting: The surface of the aged composite was sandblasted (Micro etcher –Model ER/ERC, USA) with 50 µm aluminum oxide particles at a 10-mm distance from the surface with an angle of 90° and 60 Psi pressure for 10 seconds.
2. Roughening by a bur: The surface of the aged composite was roughened by a fine-grit (40 µ) round diamond bur (801-014, DIATECH, Swiss Dental, Heerbrugg, Switzerland) with three movements on the composite surface under air and water spray. The bur was changed after roughening of five samples.
3. Er: YAG laser: The surface of the composite blocks was subjected to Er: YAG laser irradiation (Deka, Italy) at a 2490-nm wavelength, 3-W output power, 10-Hz frequency, 300-mJ energy, and 230-µs pulse duration.[21,22] The laser beam was irradiated at a 1-mm distance, and it was perpendicular to the surface of the blocks.
4. Control group: no surface preparation was accomplished.

All composite blocks were thoroughly washed for 20 seconds to eliminate the loose particles on the surface. The blocks were then dried for 10 s, etched with 37% phosphoric acid (Bisco Dental Products, Richmond, BC, Canada) for 15 seconds, and rinsed and dried with water and air spray. GC ceramic primer (GC, Tokyo, Japan) was then applied over the surface of the composite blocks, after 2 minutes it was dried with gentle air spray. This process was repeated if a glossy surface was not achieved.

Each prepared group sample was divided into two subgroups according to the type of bonding agent: (n = 1).

Subgroup 1: Clearfil SE Bond: One layer of Clearfil SE Primer (Tokuyama Dental, Tokyo, Japan) was applied, followed by 20 seconds of gentle air spray. The Clearfil SE Bond (Tokuyama Dental, Tokyo, Japan) was then used, thinned with oil-free airflow, and cured for 10 seconds.

Subgroup 2: All-Bond Universal: A thin layer of All-Bond Universal (Dental Products, Richmond, BC, Canada) was applied over the surface, thinned with oil-free airflow, and light-cured for 10 seconds.

Polofil Supra composite resin was then incrementally applied to the prepared substrate. It was then light-cured, trimmed, and finished to reach the desired shape. The repair composite blocks were then divided by a diamond disc (Microdont, Brazil, n. 34570) and a low-speed handpiece with water coolant. The samples were placed vertically relative to the diamond disc. The first section with 1-mm thickness was excluded to prevent its possible confounding effect on the results. Eight sections were obtained of each sample. The sample size was calculated according to a study by Souza et al, considering $\alpha = 0.05$, $\beta = 0.2$, and a standard deviation of 16.99.[23] All sections had an adhesive area with a cross-sectional area of approximately 1 ± 0.1 mm^2. The samples were thermocycled for 6000 cycles 5-55˚C and a dwell time of 30 seconds. Each sample was fixed with cyanoacrylate gel and the adhesive interface remained free. In order to decrease the flexural stresses, the samples were positioned parallel to the longitudinal axis of the machine as much as possible. Next, the samples were fixed to the universal testing machine (EMIC DL-1000, EMIC, Sao Jose dos Pinhais, Brazil) parallel to the direction of tensile load application, which was applied at a crosshead speed of 0.5 mm/min.

The microtensile bond strength (MTBS) was calculated. Table 1 shows the characteristics of the materials selected for this study and instructions for their application.

Statistical Analysis

Statistical analysis was carried out by two-way ANOVA. Since the difference between the groups was significant, pairwise comparisons were performed using one-way ANOVA and Tukey's test. $P < 0.05$ was considered significant.

Results

Table 2 presents the mean and standard deviation of MTBS of different groups. The interaction effect of chemically conditioned surface and mechanical surface treatment on MTBS was significant ($P < 0.001$).

The MTBS of the samples treated by air-abrasion with aluminum oxide particles (25.05 ± 5.98) and Er:YAG laser irradiation (26.16 ± 4.7) was significantly higher than that of bur preparation and control groups ($P < 0.001$). The difference between the air-abrasion and Er:YAG laser groups was not significant ($P > 0.05$). The Er:YAG laser group showed maximum MTBS and the control group showed minimum MTBS.

Surface conditioning of composite resin with the SE Bond and All-Bond significantly affected the bond strength of the Er:YAG laser and air-abrasion groups ($P < 0.001$). Sample conditioning by All-Bond yielded higher MTBS values, although this difference was not significant for bur preparation and control groups ($P > 0.05$). After surface treatments and conditioning, samples conditioned with the Er:YAG laser and All-Bond showed maximum MTBS.

Discussion

Evidence shows that the failure rate of composite restorations is annually 1.6%, while for repaired composite restorations is 5.7%.[23] Nonetheless, repairing defective restorations is a low-risk, cost-effective, and conservative approach.[24] This study compared the effect of three surface treatments and two adhesive systems on the repair bond strength of an aged microhybrid composite resin.

The repair of defective composite restorations has always been challenging due to the absence of an oxygen-inhibited layer, the effects of pH alterations, foods and drinks, and bacteria on composite restorations, and their subsequent physical and chemical degradation, water sorption of the composite polymer network that causes hygroscopic expansion of the composite mass, and hydrolytic degradation and leakage of unreacted monomers and soluble ions, which compromise the filler-resin matrix bonding interface and increase the composite mass porosity. Thus, it seems that the presence of a chemically- or mechanically-treated composite surface is imperative for a durable bond.[23,25]

In this study, the composite samples underwent accelerated aging, corresponding to about 6 months of

Table 2. Mean MTBS in Different Surface Treatment Groups (MPa)

Treatment	Bonding Agent	Mean	Standard Deviation
Air abrasion	SE bond	20.05[a]	±4.49
	All bond	24.05[b]	±5.98
Bur preparation	SE bond	17.92[c]	±3.80
	All bond	16.94[c]	±3.56
Laser	SE bond	20.22[a]	±4.24
	All bond	26.16[b]	±4.69
Control	SE bond	0.00[d]	±0.00
	All bond	1.04[d]	±3.33

Note: Identical symbols display statistical similarity.

Table 1. Characteristics of the Materials Used in This Study and Instructions for Their Application

Material	Manufacturer	Constituents	Application Instruction
Polofil Supra (A3 Shade)	VOCO, GmbH, Cuxhaven, Germany	60 vol.% microhybrid filler of 0.05 mm; Bis-GMA, UDMA, TEGDMA	Apply a 2-mm increment and light-polymerize for 40 s.
Clearfil Ceramic primer	Kuraray, Osaka, Japan	3-Trimethoxysilylpropyl methacrylate, MDP, ethanol	Apply primer over the composite for 15 s and allow to dry.
Clearfil SE Bond	Kuraray, Osaka, Japan	MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate, silanated colloidal silica, photoinitiator, water, N,N-diethanol p-toluidine bond	1. Apply the bonding agent on the surface and thin it uniformly with gentle airflow. 2. Light-polymerize for 10 s.
All Bond Universal	Bisco, Sc Haumburg, IL, USA	1. Etchant Uni-Etch: 32% phosphoric acid, benzalkonium chloride 2. Adhesive: MDP, bis-GMA, HEMA, ethanol, water, initiators	1. Apply two separate adhesive coats with a microbrush and scrub the surface for 10-15 s with each coat. Do not perform light-polymerization between the coats. 2. Completely evaporate the excess solvent by air drying and using an air syringe for a minimum of 10 s. This time would be enough for visible material movement. The surface should be homogenously clear. 3. Perform light-polymerization for 10 s.

clinical service in order to create aged composite samples with high resemblance to composite restorations aged in the oral environment.[26] The available surface treatments for old composite restorations include micromechanical and mechanical roughening by the bur, air abrasion, silica coating, and use of etchant and adhesive systems.[9] In the process of surface roughening, the superficial layer exposed to the degrading agents is removed and the surface is roughened. As a result, surface energy increases, which enhances surface wetting by the bonding agent and enables a stronger bond between the two composites at the interface.[27]

The Clearfil SE Bond and All-Bond Universal were used in this study as stated by the manufacturers' instructions. The aim to use etchant was to clean the surface, and then silane was used prior to the application of the bonding agent.[28] Silane enhances surface wetting by the bonding agent and has two functional heads. The silanol head bonds to the composite fillers, and the organofunctional group is copolymerized with the adhesive methacrylate groups. Thus, silane enhances the chemical bonding of old to new composites.[9,29,30] The silane applied prior to the bonding agent increases the wettability of the bonding agent and enhances its penetration.[1,3,19]

By application adhesives on the composite surface their monomers penetrate into the porosities of the composite surface and creates a non-polymerized layer on the surface, thus, the oxygen-inhibited layer enhances the bonding of new composite increments. The adhesive resin layer has a high attraction for inorganic fillers and bonds to hydrogen and silane.[1]

The lowest MTBS seen in the control group highlights the function of surface roughness in obtaining favorable bond strength. The highest MTBS was recorded in air abrasion and laser groups. The repair bond strength should be in the range of 15 to 25 MPa for having favorable durability.[29] Excluding the control group, all other groups showed MTBS within the acceptable range.

Air abrasion surface preparation significantly increased MTBS compared with the control group, which has been proved by the other studies.[20,30] Crumpler et al found that surface roughening can improve the bonding ability of a new composite to an old composite by micromechanical interlocking.[31] It increases the surface area by micro-retention, improves surface wetting, and enables better adhesion to composite resin.[20] At the same time, air abrasion eliminates part of the resin matrix and exposes the fillers. It enables the bonding of silane to fillers and yields higher bond strength.[32] However, some studies reported lower bond strength following air abrasion.[33] This controversy can be due to the different surface properties after air abrasion, which depend on the surface microstructure and the composition of composite resin.[32] The produced aerosols are the main drawback of sandblasting, which can be harmful to the patient and the office staff.[29]

The bond strength of laser-treated and air-abraded surfaces was the same and significantly higher than that of the diamond bur group. Erbium lasers ablate the composite resin surface by sudden evaporation and subsequent hydrodynamic loss. During the ablation process, the surface is quickly melted and the volume of the melted material changes, producing powerful, expansive forces.[16,34] The stresses produced in the composite material led to the evaporation of composite surface prominences and melted materials in the form of droplets.[17] In fact, in this process, the resin matrix is eliminated from the composite surface, leading to the formation of a rough surface and subsequent micro-retentive interlocking in composite resin. Such a surface enables better penetration of the silane and coupling agent into the aged composite. At the same time, evidence shows that the lased surface is devoid of the smear layer, which may have higher bond strength in the laser group than the bur preparation group.[16,34-36] This finding was in agreement with the results of Kimyai et al. They found that laser surface preparation was analogous to air abrasion for the repair of composite resins in vitro.[35]

Most dental clinicians prefer the diamond bur for the preparation of the enamel and composite surface before repair treatment. Thus, we used the diamond bur for surface treatment in one group in our study.[37] Our results indicated that the MTBS in the bur preparation group was lower than that in the laser and air abrasion groups. It seems that the application of etchant and adhesive cannot overcome this thick, strong layer. However, our results in this respect were different from those of Özel Bektas et al and Ahmadizenouz et al who found no significant difference between the ER:YAG laser surface preparation and the bur, which can be due to different laser parameters or selection of different composite and bonding agents and bonding tests, and they did not age their samples.[32,36]

Ahmadizenouz et al used a nanofilled composite that has a lower resin content than a microfilled composite.[32] The superficial layer in our study was probably thicker and stickier, and thus, the etchant could not clean the surface adequately.

The current results revealed a significant difference in MTBS between the two types of adhesives in the laser and air abrasion groups. But the difference between the adhesive systems in the bur preparation and control groups was not significant, which was probably due to the fact that the thick smear layer in the bur preparation group neutralized the effect of the bonding system.

Both bonding systems used in this study have active phosphate-containing functional monomers (MDP) that can form a chemical bond to oxides through their hydrophilic phosphate end and also copolymerize with resin monomers through their hydrophilic methacrylate end. The MDP-containing bonding agents activate the silane coupling agent that enhances the bond of silane to the composite surface. The higher bond strength of All-Bond can be due to the lower viscosity of this bonding agent compared with the Clearfil SE Bond, which leads to better wetting and penetration of the bonding agent into the created irregularities.[26] Also, longer drying time recommended for the universal adhesives leads to higher vaporization of solvent and subsequently higher polymerization and enhancement of mechanical properties of bonding agents.[38]

Clinical studies to assess the long-term behavior of composite resins are difficult to perform. Complete simulation of the oral environment is also impossible, and this can significantly affect the durability of restorations.[30] Exposure of composite resins to the oral environment can affect the quality of composite repair bond strength.[10] Nonetheless, in vitro studies can pave the way for future clinical studies.

Conflict of Interests

None.

Ethical Considerations

This article does not contain any studies with human participants or animals performed by any of the authors.

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