IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 24, Issue 6 Ser. 3 (June. 2025), PP 09-15
www.iosrjournals.org

An In vitro Assessment of the effects of Different Mechanical Surface Treatments on Repair Bond Strength of Aged Composites

Dr. Tirath Garg, MDS
Director, Sat Sahib Dental Clinic and Implant Centre, Patiala, Punjab, India.

Date of Submission: 27-05-2025 Date of Acceptance: 07-06-2025

Abstract

Background: Composites allow the possibility of preserving sound tooth structure during cavity preparation and represent a significant aesthetic treatment option, enabling the fabrication of restorations with a natural appearance. However, from time to time failures (discoloration, secondary caries, marginal ditching or simply fractures) of composite restorations do occur and the clinician must decide whether to replace or simply repair these restorations. Therefore, different surface treatment modalities have been used to enhance the repair bond strength of composite resins including bur roughening, etching with hydrofluoric or phosphoric acids, air abrasion, silica coating and silanization etc.

Material and Methods: In this in vitro study, 64 cylindrical shaped samples of a composite resin with specifications of 5mm in height and 4mm in diameter were prepared by layering 2mm thick increments of a composite resin (Brilliant NG, Coltene) in PVC plastic molds. The sectioned samples of 2mm in height in each group were used for analyzing surface characteristics after surface treatment using Scanning Electron Microscope. Four study groups (n=16) on the basis of surface treatment were made named Group A (control group), Group B (sample surfaces were air abraded using Prohyjet machine), Group C (An Er,Cr:YSGG laser unit was used for surface treatment), Group D (The surface of samples was roughened with a coarse (125µ) tapered diamond bur).

Results: It has been concluded that the mechanical surface treatment done with the help of diamond bur (group D) before repairing with the Brilliant Flow composite had the highest repair bond strength followed by groups C (laser), A (Acid etching) and B (air abrasion).

Key words: Composites, Repair bond strength and Surface treatments.

Introduction -

Aesthetic concepts that emerged in restorative dentistry started around 30 years ago and became the driving force in the development of some dental restorative materials **(Christensen 1997).** Composites are engineered materials consisting of at least two different classes of materials i.e. metals, ceramics, and polymers **(Ferracane 1995)** with significantly different physical and chemical properties. Composites need components that will stabilize the material. Composite resins consist of an organic resin matrix, inorganic fillers, a coupling agent and additional component, like an initiator, stabilizer and pigments to produce the different shades **(Ferracane 2001)**. Composites allow the possibility of preserving sound tooth structure during cavity preparation **(Leinfelder 1997)** and represent a significant aesthetic treatment option, enabling the fabrication of restorations with a natural appearance **(Gordan 2003)**. However, from time to time failures (discoloration, secondary caries, marginal ditching or simply fractures) of composite restorations do occur and the clinician must decide whether to replace or simply repair these restorations **(Shahdad & Kennedy 1998)**.

It is not always necessary or desirable to completely remove the defective composite restorations. Replacement frequently involves the removal of adjacent tooth structure to optimize the new enamel bond, leading to larger preparations with further more loss of tooth structure **(Söderholm & Roberts 1991)**.

A more conservative procedure i.e. repair of an existing restoration should be preferred. Repair of fractured restorations and resurfacing of discoloured restorations are accomplished by the addition of new composite over existing material **(Swift, LeValley & Boyer 1992)**. Chemical bonding between layers of resin composite relies on co-polymerization between new resin monomers and residual unreacted methacrylate groups **(Vankerckhoven et al. 1982)**. It has been suggested that the greatest reactivity of the composite surface to the formation of covalent bonds with fresh resin composite can be found during the first 24h after polymerization **(Saunders 1990)** but it tends to decrease with time **(Burtscher 1993)**.

Modification of the composite surface texture by chemical and mechanical methods has been performed in an attempt to promote a composite to composite physical interlocking **(Caliskan, Karihaloo 2004)**. Therefore, different surface treatment modalities have been used to enhance the repair bond strength of composite resins including bur roughening, etching with hydrofluoric or phosphoric acids, air abrasion, silica coating and silanization etc **(da Costa et al. 2012)**.

In recent years there has been more focus on the efficiency of lasers for composite repair bond strength **(Bektas et al. 2012)**.

Methodology -

In this in vitro study, 64 cylindrical shaped samples of a composite resin with specifications of 5mm in height and 4mm in diameter were prepared by layering 2mm thick increments of a composite resin (Brilliant NG, Coltene) in PVC plastic molds. These molds were prepared from PVC plastic pipes having 4mm diameter by cutting 5mm sections with the help BP blade no.11. Each increment was light cured for 20 seconds. Before curing the last increment, mylar strip was placed over it to achieve a smooth surface. Composite samples were removed from molds by cutting the pipes with BP blade no.11. Then each sample was cured again from all directions for 20 seconds each. In order to view surface characteristics after surface treatment, all samples from each group were sectioned into two halves of 3mm and 2mm heights with the help of a slow speed diamond disc under running water. The sectioned samples of 2mm in height in each group were used for analyzing surface characteristics after surface treatment using Scanning Electron Microscope. In order to age the composite, the sectioned samples of 3mm height were placed in distilled water and stored at room temperature for three weeks. Then they were randomly divided into four groups based on the type of surface treatment. The samples were embedded in modeling wax blocks to hold them proper during various surface treatments. Then they were embedded in acrylic resins up to a height of 2mm so that 1mm was left out and subjected to repair protocol.

The various study groups (n=16) on the basis of surface treatment as mentioned below:

Group A: Control group: In this group, no mechanical surface treatment was done. Only acid etching was done with the help of 37% orthophosphoric acid for 15 seconds on each sample.

Group B: The sample surfaces were air abraded using Prohyjet machine. Surface of samples were air abraded for 10 seconds at 40 psi pressure with 50 µm aluminium oxide particles. The tip was positioned 5 mm away from the target and perpendicular to the sample surface. Subsequently, samples were rinsed and air dried.

Group C: An Er,Cr:YSGG laser unit was used for surface treatment. This laser system emits photons at a wavelength of 2.78 µm, at a pulse of 140-200 s and a repetition rate of 20 Hz. Laser power of 2 W at 15% air level and 10% water level was used. The beam was aligned perpendicular to the target area during the exposure time of 5 seconds. Subsequently, samples were rinsed and air dried.

Group D: The surface of samples was roughened with a coarse (125µ) tapered diamond bur for 5 seconds placed tangential to surface and at a high speed with a constant water spray. Then the samples were rinsed and air dried.

Repairing composite samples

Then in all groups, etchant (Swiss Tec SL) was applied on treated surface of samples for 15 seconds, rinsed for 10 seconds and air dried for 5 seconds followed by the application of bonding agent (Swiss Tec SL Bond) with the applicator tip for 10 seconds and light cured for 20 seconds. The plastic molds for repairing composite samples were prepared by sectioning PVC plastic pipes having 4mm diameter and 4mm length with the help of BP blade no.11. Then these molds were adjusted over the treated surface of substrate composite samples. The repair composite material (flowable composite resin, Brilliant Flow, Coltene) was placed into these molds by layering 2mm thick increments. Each increment was cured for 20 seconds. The plastic molds were removed by cutting with the help of BP blade no.11. After removing the molds, repaired composites were again light cured for 20 seconds from each direction.

Aging the repaired composite setup

After polymerization, the samples were stored in distilled water at room temperature for 48 hours and then were thermocycled for 500 cycles between 5 ± 2º C and 55 ± 2º C with a dwell time of 30 seconds and transfer time of 5 seconds. Then repaired composite samples were embedded in acrylic blocks made from aluminium molds having dimensions of 4cm length, 1.5cm width and 0.5cm height.

Testing of samples

Then the repaired composite resin cylinder shaped samples were tested for shear bond strength using Universal Testing Machine. Each sample was tested in shear mode using the Instron universal testing machine at a cross head speed of 0.5mm/min. The force was applied by the chisel shaped blade of the equipment at the interface of the old and new composite resin. All results were expressed in megspascal (MPa).

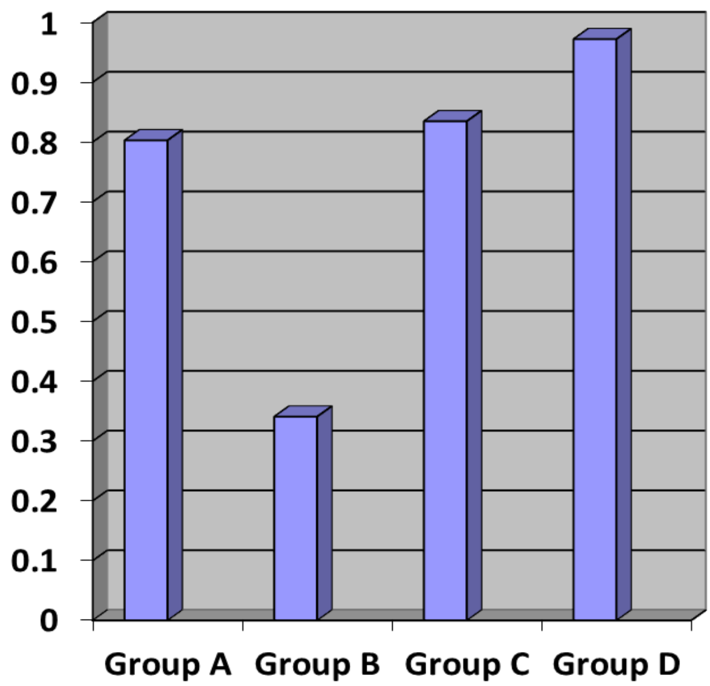
Results

Table 1 - Mean values of shear bond strength (MPa) in different groups using oneway ANOVA.

Groups	N	Mean	Std. Deviation	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
Acid Etching(A)	8	.8029	.43999	.4351	1.1708	.44	1.78
Air Abrasion(B)	8	.3408	.06500	.2864	.3951	.25	.44
Laser(C)	8	.8348	.07905	.7687	.9009	.74	.96
Bur(D)	8	.9721	.61720	.4561	1.4881	.29	1.88
Total	32	.7377	.43642	.5803	.8950	.25	1.88

Inference – The shear bond strength (SBS) values are in the descending order of D > C > A > B.

Figure 1 - Representing mean of shear bond strengths of different groups.



Inference – Mean shear bond strength values in different groups are in the following order: D > C > A > B.

Table 2- Presenting the statistically significant difference between the mean values (presented in table 1) of different groups using ANOVA test.

	Sum of Squares	Mean Square	Sig.
Between Groups	1.809	.603	.015*
Within Groups	4.095	.146	NS#
Total	5.904		

NS# - non significant
* - The mean difference is significant at the .05 level
** - highly significant

Inference- There is statistically significant difference (.015) between the mean values of different groups. However, with in groups, there is no statistical significance difference.

Table 3- Comparison of mean values of one group with the other three groups using Post hoc test.

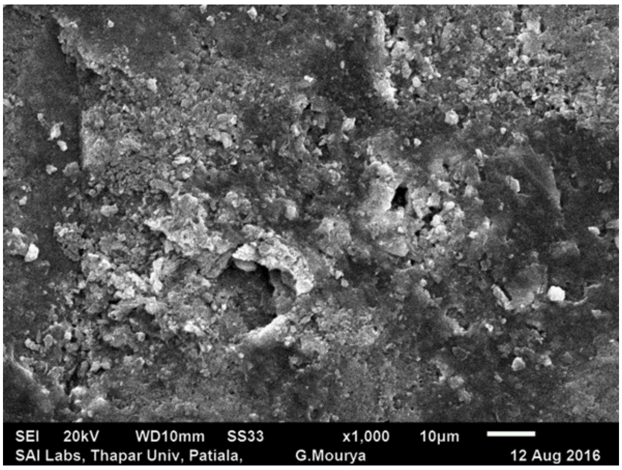
(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.
Acid Etching(A)	**Air Abrasion(B)**	.46215	.19122	.135
	Laser (C)	-.03187	.19122	1.000
	Bur (D)	-.16917	.19122	1.000
Air Abrasion(B)	**Laser (C)**	-.49402	.19122	.092
	Bur (D)	-.63131(*)	.19122	.016*
Laser(C)	**Bur(D)**	-.13730	.19122	1.000

* The mean difference is significant at the .05 level.
** highly significant

Inference- There is statistically significant difference between group B and group D.

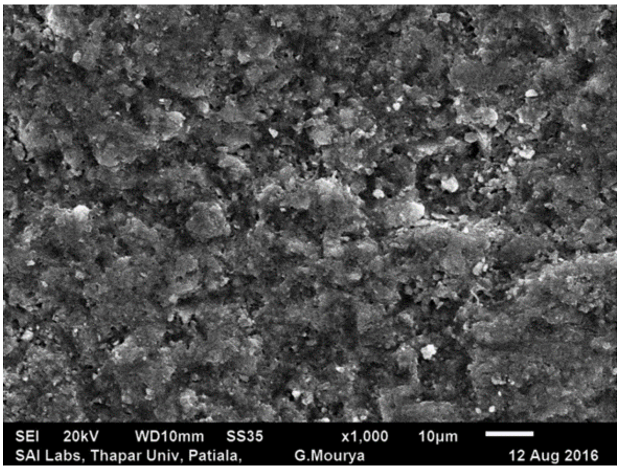
Conclusion – The mechanical surface treatment done with the help of diamond bur (group D) before repairing with the Brilliant Flow composite has shown the highest repair bond strength.

Scanning Electron Microscope Images



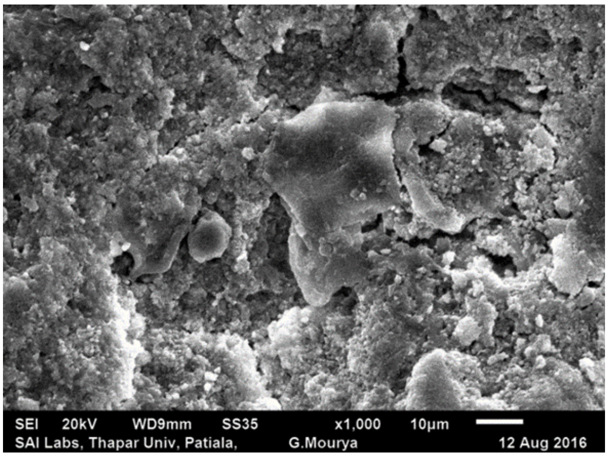
Photograph 1. SEM micrograph (secondary electron mode at x1000) of resin composite surface without surface treatment (Group A – Acid etching).

Etching with 37% phosphoric acid did not cause any morphologic change in the composite surface, apart from producing a cleaning effect.



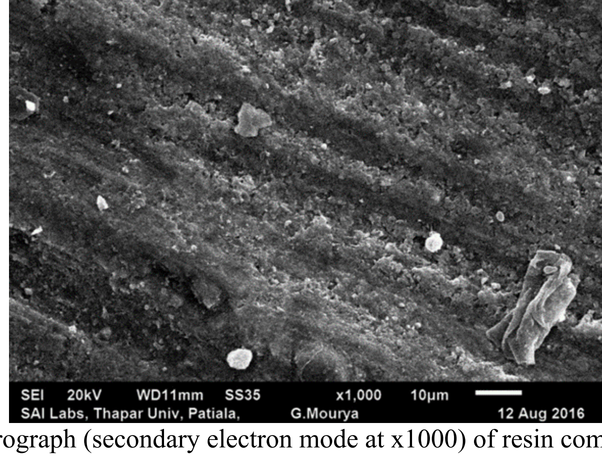
Photograph 2. SEM micrograph (secondary electron mode at x1000) of resin composite surface treated with airborne particle abrasion with 50μm aluminum oxide particles.

Air abrasion with 50μm aluminium oxide particles produced scratches and grooves covered with streaks of smeared matrix.



Photograph 3. SEM micrograph (secondary electron mode at x1000) of resin composite surface treated with Er,Cr:YSGG laser.

In the laser group, cleaned ablated surfaces with no smear layer production could be seen. The surfaces treated by Er,Cr:YSGG laser showed irregular and microporous surfaces.



Photograph 4. SEM micrograph (secondary electron mode at x1000) of resin composite surface treated with diamond bur.

On the composite substrate after roughening with a coarse-grit diamond bur - roughened, highly irregular surface topography, with resin composite block asperities created among numerous microretentive fissures.

Discussion

Effect of different mechanical surface treatments on the repair bond strength of aged composites

Resin based dental composites are the materials of choice for restoring anterior and posterior teeth. The annual failure rates of anterior and posterior composite restorations commonly vary between 1% and 4% **(Baldissera et al. 2013, Da Rosa Rodolpho et al. 2011, Demarco et al. 2015)**. Patient characteristics, professional technique, experience and material selection are the factors known to potentially affect the clinical performance of dental restorations **(Demarco et al. 2015)**. Restorations in patients with higher risk for caries lesions or occlusal stresses are expected to show increased failure rates **(Opdam et al. 2010, van de Sande et al. 2013)**. In case of composite restoration failures, the dentist has three main options to deal with the defective restoration: to refurbish, repair or replace the composite **(Fernandez et al. 2015)**. Refurbishing means that no material or dental structure will be removed and additional restorative material will be added to fix the restoration, refinishing and repolishing are carried out to improve anatomy and surface properties. Repair is a procedure that involves partial removal of the defective part of the restorative material, which is then repaired with new material to complete the restoration. In contrast to refurbishing and repairing, which might be considered more conservative approaches **(Moncada et al. 2009)**, replacing a restoration involves complete removal of the restoration (even portions that might appear clinically acceptable) for placement of new material. In this approach, it is virtually impossible to avoid removal of sound tooth structure during cavity preparation **(Mjor et al. 1998)**, increasing the risk of pulp injury, tooth fracture and even need for endodontic treatment. Studies **(Fernandez et al. 2015, Moncada et al. 2009)** have shown that composite repairs might improve the clinical longevity of dental restorations. However, there is no gold standard protocol or materials established for treating the aged composite surfaces before repair.

Bonding a fresh resin composite to aged composite restorations in the oral cavity is challenging because during aging of composite materials in the oral cavity, number of double bonds and active radicals that enable chemical bonding between the existing and the repair composite material decreases **(Dall'Oca et al. 2007, Tezvergil et al. 2004)**.

To ensure a successful repair, it is important that the bonded interface may be capable of withstanding debonding forces. Thermocycling and water storage represent a common way to test dental materials in laboratory conditions in order to predict their validity for clinical use **(Sideridou et al. 2004)**. Exposing the composite to composite bonded specimens to water may expedite the degradation of those bonds as well as accelerate degradation phenomena of the resin based materials involved **(Söderholm et al. 1984, Turssi et al. 2002, Pandey et al. 2005).**

This test involves subjecting specimens to extreme temperatures. **Özcan (2007)** reported that because thermocycling was more effective in the degradation of the composite resins than other aging methods, it represents a more challenging condition for the composite tested. Several factors affect the thermal cycling on the bond strength of adhesive systems, including temperature settings, dwell time and the number of cycles **(Amaral 2007)**. According to ISO standards, 500 thermocycles in water temperatures between 5°C and 55°C are considered to be an appropriate test for aging dental materials **(Xie et al. 2010)**.

When repairing the existing composite restoration, it is first necessary to prepare its surface mechanically to remove the outer layer of the aged composite that is most affected by saliva or other media and to create an appropriate surface morphology for micromechanical bonding **(Hannig et al. 2006, Soderholm, Roberts 1991)**.

Mechanical and/or chemical treatments to roughen the surface include roughening with diamond bur **(Kupiec, Barkmeier 1996)**, carbide bur (Crumpler et al. 1989), silicon carbide paper **(Tezvergil, Lassila & Vallittu 2003)**, green carborundum stone **(Brosh et al. 1997)**, air abrasion with 50 μm aluminum oxide particles **(Swift, LeValley & Boyer 1992)**, etching with 37% phosphoric acid gel **(Crumpler et al. 1989)**, hydrofluoric acid **(Brosh et al. 1997)** and 1.23% acidulated phosphate fluoride gel **(Swift, LeValley & Boyer 1992)**. Diamond bur is preferred by most clinicians for preparing enamel and composite surface prior to acid etching. It produces more retentive features on the surface to be reapired **(Acharya, Manjunath 2012)**. In our study also, diamond bur treatment produced the highest repair bond strength in both subgroups (Table 1).

Air abrasion or sandblasting is an old technology that is finding a new place in modern science based dentistry. It uses 50μm aluminium oxide particles at 40 Psi pressure and is found effective to improve the repair bond strength **(Trajtenberg, Powers 2004)**. But our study, repair bond strength obtained after air abrasion was least as compared to other groups (Table 1, Figure 1).

The use of acid etching on ground surfaces removes the smear debris, exposing the underlying surface and fillers **(Fawzy, El-Askary & Amer 2008)**. Acid etching is a mandatory procedure for resin restorations to bond to enamel and dentin **(Yesilyurt et al. 2009)**, so etching was used in the repair procedure in this study. The acid etching procedure, performed in similar research protocols **(Shahdad, Kennedy 1998, Lucena-Martín et al. 2001 & Bonstein et al. 2005)** was unable to produce any significant morphologic changes in the retentive pattern of the resin matrix, as confirmed by the similar bond strengths in comparison to the un-etched groups. In our study, repair bond strength obtained after acid etching was less as compared to diamond bur and laser groups .This confirms that mechanical retention plays the most important role in repair bond strength and that 37% phosphoric acid probably exercises a superficial cleaning effect on the composite surface.

Kimyai et al. (2010) reported that Er,Cr:YSGG laser treated laboratory composite resulted in higher repair bond strength as compared to diamond bur. However, in our study the results portrait otherwise i.e. repair bond strength obtained after laser treatment was less as compared to diamond bur group. The differences in study findings might be related to the type of composites used, given that the composition of composite resin can affect the efficacy of mechanical surface treatments **(Lucena-Martín et al. 2001, Swift, Cloe & Boyer 1991)**. Dental composite filler particles scatter the energy of a laser, whereas various components of the resin based compartment absorb laser energy **(Alexander, Xie & Fried 2002)**. Many investigators have reported the ability of the Er:YAG laser to ablate tooth structure, which is indicated for selective removal of carious lesions, cavity preparation and modification of tooth structure surfaces **(Korkmaz et al. 2009)**. For this reason, a laser can be viewed as a conservative alternative to a mechanical surface treatment modality for composite repairing procedures **(Lizarelli, Moriyama & Bagnato 2003)**. In contrast to the bur, lasers ablate the restorative materials without smear layer formation **(Lizarelli, Moriyama & Bagnato 2003)**. Due to the negative effect of smear layer on bonding, lasing is thought to provide a higher bonding strength than grinding with bur **(Kimyai et al. 2010)**.

Water sorption also has a complex and deleterious effect on the integrity and properties of polymer matrix composites, including flexural and repair strengths **(Matsou et al. 1991)**. Presumably, the long period of aging in the present study makes it a much more realistic simulation for repair of older composite restorations.

Analysis of surface topography using Scanning Electron Microscopy Analysis : Additional composite substrates were prepared and surface treated similarly to those in experimental groups. The specimens were mounted on aluminium stubs, sputter-coated with gold (SC7620 Sputter Coater, Polaron Range, Quorum Technologies, England) and observed using a scanning electron microscope (JSM 6510LV, JEOL, Tokyo, Japan). Micrographs were taken at standardized magnifications (1000X) in order to document the surface texture created by the different mechanical treatments performed in each study group.
SEM examination of the treated composite substrates revealed different surface textures.

Acid etching with 37% phosphoric acid did not cause any morphologic change in composite surface apart from producing a cleaning effect (Photograph 1). This might have accounted for low repair bond strength values in acid etching group in both subgroups.

Air abrasion with 50 µm aluminium oxide particles produced scratches and grooves covered with streaks of smeared matrix (Photograph 2). In a study done by **Papacchini et al. (2007)**, they concluded that air abrasion of a cured composite surface with 50µm aluminium oxide produced statistically higher bond strengths. But in our study, it produced least repair bond strength in both subgroups (Table 1).

In the laser group, cleaned ablated surfaces with no smear layer production could be seen. The surfaces treated by Er,Cr:YSGG laser showed irregular and micro porous surfaces (Photograph 3). **Kimti et al. (2010)** found that Er:Cr:YSGG laser was confirmed to be effective solution for composite repair. In our study, repair bond strength obtained by using laser treatment was less as compared to diamond bur group in both subgroups (Table 1).

Diamond bur roughening was able to produce more micro-retentive features (Photograph 4) increasing the surface area available for wetting and bonding by the adhesive resin. This might have accounted for the strongest interfacial bond achieved in different groups in the present study (Table 1, Figure 1). Studies done by previous investigators **(Brosh et al. 1997, Yesilyurt et al. 2009, Joulaei et al. 2012 and Oskoee et al. 2014)** have also reported that mechanical surface treatment done by using diamond bur roughening has yielded highest repair bond strength values.

Conclusion

Within the limitations of this study, it was concluded that the mechanical surface treatment done with the help of diamond bur (group D) before repairing with the Brilliant Flow composite had the highest repair bond strength followed by groups C, A and B (Table 1 & Figure 1). There is statistically significant difference present between the groups B and D (Table 3).

References

Acharya, GS, Manjunath, M 2012, 'The effect of surface treatments & bonding regimens on microtensile bond strengths of repaired composite: An in vitro study', *Journal of Conservative Dentistry*, vol. 15, no. 4, pp. 383-387.

Alexander, R, Xie, J & Fried, D 2002, 'Selective removal of residual composite from dental enamel surfaces using the third harmonic of a Q-switched Nd:YAG laser', *Lasers in Surgery & Medicine*, vol. 30, no. 3, pp. 240–245.

Amaral, FL, Colucci, V, Palma-Dibb, RG & Corona, SA 2007, 'Assessment of in vitro methods used to promote adhesive interface degradation: a critical review', *Journal of Esthetic & Restorative Dentistry*, vol. 19, no. 6, pp. 340–353.

Baldissera, RA, Correa, MB, Schuch, HS, Collares, K, Nascimento ,GG, Jardim, PS, Moraes RR, Opdam NJ & Demarco FF 2013, 'Are there universal restorative composites for anterior & posterior teeth', *Dentistry*, vol. 41, no.11, pp. 1027–1035.

Bektas, OO, Eren, D, Herguner Siso, S & Akin, GE 2012, 'Effect of thermocycling on the bond strength of composite resin to bur & laser treated composite resin', *Lasers in Medical Science,* vol. 27, no. 4, pp. 723–728.

Bonstein, T, Garlapo, D, Donarummo, J & Bush, PJ 2005, 'Evaluation of varied repair protocols applied to aged composite Resin', *The Journal of Adhesive Dentistry*, vol. 7, no. 1, pp. 41–49.

Brosh, T, Pilo, R, Bichacho, N & Blustein, R 1997, 'Effects of combination of surface treatments & bonding agent on the bond strength of repaired composites', *Journal of Prosthetic Dentistry*, vol. 77, no. 2, pp. 122-126.

Burtscher, P 1993, 'Stability of radicals in cured composite materials', *Dental Materials*, vol. 9, no. 4, pp. 218-221.

Caliskan, S, Karihaloo, BL 2004, 'Effect of surface roughness, type & size of model aggregates on the bond strength of aggregate/mortar interface', *Interface Science*, vol. 12, no. 4, pp. 361-374.

Christensen, GJ 1997, 'The state of the art in esthetic restorative dentistry', *Journal of the American Dental Association,* vol.128, no. 9, pp. 1315-1317.

Crumpler, DC, Bayne, SC, Sockwell, S, Brunson, D & Roberson, TM 1989, 'Bonding to resurfaced posterior composites', *Dental Materials*, vol. 5, no. 6, pp. 417-24.

da Costa, TR, Serrano, AM, Atman, AP, Loguercio, AD & Reis A 2012, 'Durability of composite repair using different surface treatments', *Journal of Dentistry,* vol. 40, no. 6, pp. 513-521.

Da Rosa Rodolpho, PA, Donassollo, TA, Cenci, MS, Loguercio, AD, Moraes, RR, Bronkhorst EM, Opdam NJ & Demarco FF 2011, '22-Year clinical evaluation of the performance of two posterior composites with different filler characteristics', *Dental Materials*, vol. 27, no. 10, pp. 955–63.

Dall'Oca, S, Papacchini, F, Goracci, C, Cury, AH, Suh, BI, Tay FR, Polimeni A & Ferrari M 2007, 'Effect of oxygen inhibition on composite repair strength over time', *Journal of Biomedical Materials Research*, vol. 81, no. 2, pp. 493-498.

Demarco, FF, Collares, K, Coelho-de-Souza, FH, Correa, MB, Cenci, MS, Moraes, RR & Opdam, NJ 2015, 'Anterior composite restorations: A systematic review on long-term survival & reasons for failure', *Dental Materials*, vol. 31, no. 10, pp. 1214–24.

Fawzy, AS, El-Askary, FS & Amer, MA 2008, 'Effect of surface treatments on the tensile bond strength of repaired water-aged anterior restorative micro-fine hybrid resin composite', *Journal of Dentistry*, vol. 36, no. 12, pp. 969–976.

Fernandez, E, Martin, J, Vildosola, P, Oliveira Junior, OB, Gordan, V, Mjor I, Bersezio, C, Estay, J, de Andrade, MF & Moncada, G 2015, 'Can repair increase the longevity of composite resins? Results of a 10-year clinical trial', *Journal of Dentistry*, vol. 43, no. 2, pp. 279–86.

Ferracane, JL 1995, 'Current trends in dental composites', *Critical Reviews in Oral Biology & Medicine',* vol. 6, no. 4, pp. 302-318.

Ferracane, JL 2001, *Materials in dentistry: principles & applications*, Lippincott Williams & Wilkins, Philadelphia, USA.

Gordan, VV 2001, 'Clinical evaluation of replacement of class V resin based composite restorations', *Journal of Dentistry*, vol. 29, pp. 485-488.

Hannig, C, Laubach, S, Hahn, P & Attin, T 2006, 'Shear bond strength of repaired adhesive filling materials using different repair procedures', *The Journal of Adhesive Dentistry*, vol. 8, no. 1, pp. 35-40.

Joulaei, M, Bahari, M, Ahmadi, A & Oskoee, SS 2012, 'Effect of Different Surface Treatments on Repair Micro-shear Bond Strength of Silica & Zirconia-filled Composite Resins', *Journal of Dental Research, Dental Clinics, Dental Prospects*, vol. 6, no. 4, pp. 131-137.

Kimyai, S, Mohammadi, N, Navimipour, EJ & Rikhtegaran, S 2010, ‘Comparison of the Effect of Three Mechanical Surface Treatments on the Repair Bond Strength of a Laboratory Composite’, *Photomedicine & Laser Surgery,* vol. 28, no. 2, pp. 25–30.

Korkmaz, Y, Ozel, E, Attar, N, Bicer, CO & Firatli, E 2010, ‘Microleakage & scanning electron microscopy evaluation of all-in-one self-etch adhesives & their respective nanocomposites prepared by erbium: yttrium-aluminum-garnet laser & bur’, *Lasers in Medical Science*, vol. 25, no. 4, pp. 493–502.

Leinfelder, KF 1997, ‘A conservative approach to placing posterior composite Lizarelli, RF, Moriyama, LT & Bagnato, VS 2003, ‘Ablation of composite resins using Er:YAG laser–comparison with enamel & dentin’, *Lasers in Surgery & Medicine*, vol. 33, no. 2, pp. 132–139.

Lucena-Martín, C, González-López, S & Navajas-Rodríguez de Mondelo, JM 2001, ‘The effect of various surface treatments & bonding agents on the repaired strength of heat-treated composites’, *The Journal of Prosthetic Dentistry*, vol. 86, no. 5, pp. 481–488.

Matsou, HM, Kouma, AK, Papadoyiannis, Y & Pahine, ST 1991, ‘An in vitro study of the tensile strength of composite resins repaired with the same or another composite resin’, *Quintessence International Journal,* vol. 22, no. 6, pp. 475-481.

Mjor, IA, Reep, RL, Kubilis, PS & Mondragon, BE 1998, ‘Change in size of replaced amalgam restorations: a methodological study’, *Operative Dentistry,* vol. 23, no. 5, pp. 272–277.

Moncada, G, Martin, J, Fernandez, E, Hempel, MC, Mjor, IA & Gordan, VV 2009, ‘Sealing, refurbishment & repair of Class I & Class II defective restorations: a three-year clinical trial’, *Journal of American Dental Association*, vol. 140, no. 4, pp. 425–432.

Opdam, NJ, Bronkhorst, EM, Loomans, BA & Huysmans, MC 2010, ‘12-year survival of composite vs. amalgam restorations’, *Journal of Dental Research*, vol. 89, no. 10, pp. 1063–67.

Oskoee, PA, Kimyai, S, Talatahari, E, Rikhtegaran, S, Pournaghi-Azar, F & Sajadi Oskoee, J 2014, ‘Effect of mechanical surface treatment on the repair bond strength of the silorane-based composite resin’, *Journal of Dental Research, Dental Clinics & Dental Prospects*, vol. 8, no. 2, pp. 61- 66.

Ozcan, M, Barbosa, SH, Melo, RM, Galhano, GA & Bottino, MA 2007, ‘Effect of surface conditioning methods on the microtensile bond strength of resin composite to composite after aging conditions’, *Dental Materials*, vol. 23, no. 10, pp. 1276-82.

Pandey, JK, Reddy, KR, Kumar, AP & Singh, RP 2005, ‘An overview on the degradability of polymer nanocomposites’, *Polymer Degradation & Stability Journal*, vol. 88, no. 2, pp. 234-250.

Papacchini, F, Oca, SD, Chieffi N, Cecilica, G, Sadek, F T, Suh, BI, Tay, FR, & Ferrari, M 2007, ‘Composite-to-Composite Microtensile Bond Strength in the Repair of a Microfilled Hybrid Resin: Effect of Surface Treatment & Oxygen Inhibition’, *The Journal of Adhesive Dentistry*, vol. 9, no. 1, pp. 25-31.

Saunders, WP 1990, ‘Effect of fatigue upon the interfacial bond strength of repaired composite resins’, *Journal of Dentistry*, vol. 18, no. 3, pp. 158-162.

Shahdad, SA, Kennedy JG 1998, ‘Bond strength of repaired anterior composite resins: an in vitro study’, *Journal of Dentistry*, vol. 26, no. 8, pp. 685-694.

Sideridou, T, Achilias, DS & Kyrikou, E 2004, ‘Thermal expansion characteristics of light-cured dental resins & resin composites’, *Biomaterials*, vol. 25, no. 15, pp. 3087-3097.

Soderholm, KJ, Roberts, MJ 1991, ‘Variables influencing the repair strength of dental composites’, *Scandinavian Journal of Dental Research*, vol. 99, no. 2, pp. 173-180.

Söderholm, KJ, Zigan, M, Ragan, M, Fischlschweiger, W & Bergman, M 1984, ‘Hydrolytic degradation of dental composites’, *Journal of Dental Research*, vol. 63, no. 10, pp. 1248-1254.

Swift EJ, Jr, LeValley, BD & Boyer, DB 1992, ‘Evaluation of new methods for composite repair’, *Dental Materials*, vol. 8, no. 6, pp. 362-365.

Tezvergil, A, Lassila, LV, Yli-Urpo, A & Vallittu, PK 2004, ‘Repair bond strength of restorative resin composite applied to fiber reinforced composite substrate’, *Acta Odontologica Scandinavica*, vol. 62, no. 1, pp. 51-60.

Tezvergil, A, Lassila, LVJ & Vallittu, PK 2003, ‘Composite-composite repair bond strength: Effect of different adhesion primers’, *Journal of Dentistry*, vol. 31, no. 8, pp. 521-525.

Trajtenberg, CP, Powers, JM 2004, ‘Bond strengths of repaired laboratory composites using three surface treatments & three primers’, *American Journal of Dentistry*, vol. 17, no. 2, pp. 123-126.

Turssi, CP, Hara, AT, Serra, MC & Rodrigues, AL, Jr 2002, ‘Effect of storage media upon the surface micromorphology of resin-based restorative materials’, *Journal of Oral Rehabilitation*, vol. 29, no. 9, pp. 864-871.

Van de Sande, FH, Opdam, NJ, Rodolpho, PA, Correa, MB, Demarco , FF & Cenci, MS 2013, ‘Patient risk factors' influence on survival of posterior composites’, *Journal of Dental Research*, vol. 92, no. 7, pp. 78S–83S.

Vankerckhoven, H, Lambrechts, P, Van Beylen, M, Davidson, CL & Vanherle, G 1982, 'Unreacted methacrylate groups on the surfaces of composite resins', *Journal of Dental Research*, vol. 61, pp. 791-795.

Xie, C, Han, Y, Zhao, XY, Wang, ZY & He, HM 2010, 'Microtensile bond strength of one & two-step self-etching adhesives on sclerotic dentin: the effects of thermocycling', *Operative Dentistry*, vol. 35, no. 5, pp. 547–555.

Yesilyurt, C, Kusgoz, A, Bayram, M & Ulker, M 2009, 'Initial repair bond strength of a nano-filled hybrid resin: effect of surface treatments & bonding agents', *Journal of Esthetic & Restorative Dentistry*, vol. 21, no. 4, pp. 251–260.