

Comparative Evaluation of Different Surface Treatments and Adhesive Systems on the Repair Microshear Bond Strength of Aged Nanohybrid Composite Resin: An In Vitro Study

Running title: Surface treatment and adhesive selection in composite repair

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Abstract

Introduction: Repairing a defective composite restoration, rather than replacing it, preserves tooth structure and can extend the service life of the restoration. The weak point of any repair is the junction between old and new material, because an aged composite surface offers very few unreacted methacrylate groups for the fresh resin to copolymerise with. This study compared two mechanical surface treatments and two adhesive systems for the repair of aged nanohybrid composite resin.

Materials and methods: Eighty standardised nanohybrid composite specimens were fabricated from a three-dimensionally printed master model using a silicone mould, aged by 5,000 thermocycles between 5°C and 55°C, and randomly allocated to four groups (n = 20 each): Group I, diamond bur + Clearfil SE Bond; Group II, diamond bur + G-Premio Bond; Group III, 50-µm aluminium oxide air abrasion + Clearfil SE Bond; and Group IV, air abrasion + G-Premio Bond. All treated surfaces were cleaned with 35% phosphoric acid before the adhesive was applied, and a repair cylinder 1 mm in diameter and 2 mm in height was then built on each surface using standard silicone mould. Microshear bond strength (µSBS) was measured in a universal testing machine at 1 mm/min, and fractured surfaces were classified under a stereomicroscope. Data were analysed using one-way and two-way analysis of variance (ANOVA) at $\alpha = 0.05$.

Results: Mean µSBS was highest in Group II (14.39 ± 1.18 MPa), followed by Group I (13.14 ± 1.30 MPa), Group IV (11.42 ± 0.80 MPa) and Group III (9.24 ± 0.78 MPa), and the four groups differed significantly ($F = 92.098$, $p < 0.001$). Two-way ANOVA confirmed significant main effects of surface treatment ($F = 217.985$, $p < 0.001$) and adhesive system ($F = 54.314$, $p < 0.001$), together with a significant interaction between the two ($F = 3.996$, $p = 0.049$). Mixed failure was the most frequent mode in Groups II, III and IV (50%–60%), whereas adhesive failure dominated in Group I (60%).

Conclusions: Under the conditions tested, diamond bur roughening produced higher repair bond strength than aluminium oxide air abrasion, and G-Premio Bond outperformed Clearfil SE Bond on both surfaces. The combination of diamond bur roughening and the universal adhesive gave the strongest repair of aged nanohybrid composite, while air abrasion followed by the two-step self-etch adhesive gave the weakest.

Keywords: Composite repair, Microshear bond strength, Aged composite resin, Air abrasion, Diamond bur, Universal adhesive, Self-etch adhesive, Thermocycling, Nanohybrid composite, Minimally invasive dentistry

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Introduction

Resin composite is now the default material for direct restorations in both anterior and posterior teeth, and its long-term record is good. In a meta-analysis built on individual participant data from 12 longitudinal studies, Opdam et al. reported annual failure rates of 1.8% at five years and 2.4% at 10 years for posterior composites, with the risk of failure rising in patients at high caries risk and in restorations that involved more surfaces.¹ Low as these figures are, they describe a steady attrition.

Over time, restorations chip, wear, stain at the margins or fracture, and the clinician is left with a decision that recurs thousands of times a day in general practice; replace the whole restoration, or repair only the part that has failed.²

Replacement is not a neutral choice. Cutting out a largely serviceable restoration inevitably removes some sound tooth tissue with it, enlarges the preparation and moves the tooth one step further along the restorative cycle. Repair avoids much of

this, and it has held up well in clinical studies. Gordan et al. followed defective composite restorations for seven years and found that repair and other minimally invasive alternatives were viable substitutes for complete replacement.³ A 10-year double-blind trial by Fernández et al. reached a similar verdict and recommended repair whenever it was clinically indicated, because repaired restorations behaved much like replaced ones on the clinical parameters assessed.⁴ Practice-based data point the same way, suggesting that repair can lengthen the survival of direct posterior restorations,⁵ and current clinical guidance treats repair as the preferred option for localised defects.^{2,6} The difficulty lies at the interface. When a clinician places one increment of composite over another during a routine restoration, the two layers copolymerise through an oxygen-inhibited surface layer that is rich in unreacted monomer. An aged restoration offers nothing comparable. Once a composite has spent months or years in the mouth, its resin matrix has absorbed water, residual monomers have leached out, the degree of conversion at the surface has risen and fillers near the surface may have lost their silane coupling.⁷⁻⁹ Nagano et al. showed that water aging of the adherend composite alone was enough to reduce repair microshear bond strength,⁷ and Wendler et al. recorded a clear increase in degree of conversion after 30 days of water storage of a nanohybrid substrate.⁹ Any repair protocol therefore has to manufacture the retention that the aged surface no longer provides, through micromechanical roughening and through an adhesive that wets and penetrates the roughened surface.⁶ A systematic review by Kanzow et al. found, however, that the repair protocols described in the literature vary widely from one study to the next, and no single sequence has emerged as the standard.¹⁰ Two mechanical treatments dominate clinical practice. Roughening with a diamond bur is quick, needs no extra equipment and produces macroscopic grooves along with finer secondary scratches, and the grit of the bur has itself been investigated as a variable in repair strength.¹¹ Air abrasion with 50- μ m aluminium oxide particles produces a finer and more uniform microretentive pattern and cleans the surface at the same time, but it requires an intraoral blasting device and good aerosol control.⁶ Comparative studies have not settled which is better. Özcan et al. showed that both the aging method and the type of substrate (microhybrid, nanohybrid or nanofilled) altered the response to surface conditioning,^{12,13} and Loomans et al., after testing several repair techniques on composites of different compositions, concluded that no single technique was optimal for all of them.¹⁴ Almutairi et al., whose design informed the present work, repaired thermocycled Tetric EvoCeram, Filtek Ultimate and Neo Spectra ST HV with a flowable composite and

found that silica coating and tungsten carbide burs gave higher shear bond strength than a diamond-abrasion simulation or an untreated control, with adhesive failures concentrated in the latter two groups.¹⁵ In contrast, a network meta-analysis of 26 in vitro studies that used rigorous aging protocols ranked diamond bur roughening, followed by silane and an adhesive, among the most effective approaches for long-term repair strength.¹⁶

The adhesive is the second half of the problem. Clearfil SE Bond (Kuraray Noritake Dental Inc., Tokyo, Japan) is a two-step self-etch system whose primer contains 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) and a separate hydrophobic bonding resin has made it a laboratory and clinical benchmark for bonding to tooth tissue.^{17,18} G-Premio Bond (GC Corporation, Tokyo, Japan) is a one-bottle universal adhesive that combines 10-MDP with 4-methacryloxyethyl trimellitic acid (4-META) and a thiophosphate monomer (MDTP) in an acetone-based, HEMA-free formulation. Universal adhesives have attracted interest for repair because a single bottle can be applied to composite, enamel and dentin exposed in the same preparation.¹⁸ Their performance on aged composite, however, has not been uniform. Yilmaz et al. reported that G-Premio Bond needed mechanical roughening of the aged composite, because without it repair strength stayed significantly below that of the unaged positive control,¹⁹ Yin et al. found that repair performance depended on the particular adhesive and that universal adhesives raised repair bond strength irrespective of etching mode,²⁰ and Altinci et al. observed that universal-adhesive repairs of nanohybrid composites were comparatively stable under thermocycling.²¹

What remains unclear is how the choice of mechanical treatment and the choice of adhesive act together on an aged nanohybrid substrate, and whether a given adhesive performs equally well on a bur-cut surface and on an air-abraded one. A factorial design is well suited to that question because it can separate the two main effects from their interaction. The present in vitro study was therefore undertaken to compare the repair microshear bond strength (μ SBS) and failure mode of aged nanohybrid composite resin after diamond bur roughening and aluminium oxide air abrasion, each combined with either Clearfil SE Bond or G-Premio Bond. Three null hypotheses were tested; surface treatment would have no effect on repair μ SBS; the adhesive system would have no effect on repair μ SBS and the two factors would not interact.

Aim

To evaluate the effect of different surface treatment methods and adhesive systems on repair bond strength of aged composite resin.

Materials and Methods

Study design, setting and ethical approval

This in vitro study was conducted in the Department of Conservative Dentistry and Endodontics, Government Dental College and Hospital, Jamnagar, Gujarat, India. Ethical approval was obtained from the Institutional Ethics Committee (Reference No. 107/02/2026) before the study began. The study followed a 2×2 factorial design in which surface treatment (diamond bur roughening and aluminium oxide air abrasion) and adhesive system (Clearfil SE Bond and G-Premio Bond) were the two independent variables, and repair microshear bond strength (μ SBS) was the primary outcome. Failure mode was recorded as a secondary outcome. The four experimental groups are shown in Table 1, and the materials used are listed in Table 2.

Table 1. Experimental groups (2×2 factorial design; N = 80)

Group	Surface treatment	Adhesive system	n
Group I	Diamond bur roughening	Clearfil SE Bond (two-step self-etch)	20
Group II	Diamond bur roughening	G-Premio Bond (one-step universal)	20
Group III	Aluminium oxide air abrasion (50 μ m)	Clearfil SE Bond (two-step self-etch)	20
Group IV	Aluminium oxide air abrasion (50 μ m)	G-Premio Bond (one-step universal)	20

Table 2. Materials used in the study

Material	Type / manufacturer	Principal components	Application (manufacturer's instructions)
Tetric N-Ceram Nanohybrid Composite	Nanohybrid resin composite; Ivoclar Vivadent, Liechtenstein	Resin matrix and filler	Placed in the mould and light-cured; used for both substrate and repair
Clearfil SE Bond	Two-step self-etch adhesive; Kuraray Noritake	Primer: 10-MDP, HEMA, hydrophilic	Primer applied and left undisturbed, gently air-

Material	Type / manufacturer	Principal components	Application (manufacturer's instructions)
	Dental Inc., Tokyo, Japan	dimethacrylate, photoinitiator, water. Bond: 10-MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate, photoinitiator, silanated colloidal silica	dried; bonding resin applied, gently air-thinned and light-cured
G-Premio Bond	One-step universal adhesive; GC Corporation, Tokyo, Japan	10-MDP, 4-META, MDTP, methacrylate monomers, acetone, water, photoinitiators, fine silica	Applied, left undisturbed, dried under gentle air pressure and light-cured
Phosphoric acid gel	37% phosphoric acid; N-etch, Ivoclar Vivadent, Schaan, Liechtenstein	Phosphoric acid 37%	Applied for 20 s, rinsed and air-dried
Aluminium oxide powder	50 μ m Al_2O_3 particles;	Aluminium oxide particles	2.5 bar, 10 mm working distance, 10 s

10-MDP, 10-methacryloyloxydecyl dihydrogen phosphate; HEMA, 2-hydroxyethyl methacrylate; Bis-GMA, bisphenol A-glycidyl methacrylate; 4-META, 4-methacryloyloxyethyl trimellitic acid; MDTP, methacryloyloxydecyl dihydrogen thiophosphate. Compositions as reported by the manufacturers.

Sample size

The sample size was calculated using G*Power software, version 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Germany), on the basis of previously published repair bond-strength data. With α set at 0.05 and a power of 80%, the minimum number of specimens required per group was determined, and this was increased to 20 specimens per group to allow for losses during specimen fabrication and testing. A total of 80 specimens were therefore included.

Specimen preparation

To keep specimen geometry identical across groups, a master model of cylindrical specimens measuring 2×2 mm was designed and fabricated using 3D printing technology. Negative replicas of these master specimens were then prepared using addition silicone putty material to obtain standardized moulds for specimen preparation (Figure 1). The nanohybrid composite resin was packed into the moulds using an incremental technique and was light-cured for 20 seconds using an LED curing unit (Woodpecker RTA Mini S; intensity ≥ 1000 mW/cm²; wavelength 430–480 nm). A Mylar strip was placed over the composite surface during curing to obtain a smooth, standardized and oxygen-inhibition layer free surface. After removal from the moulds, all specimens were post-cured from all directions for 40 seconds to ensure complete polymerization.

Each specimen was finished to a standard form and stored in distilled water at 37°C for 24 hours testing in accordance with standardized laboratory protocols.

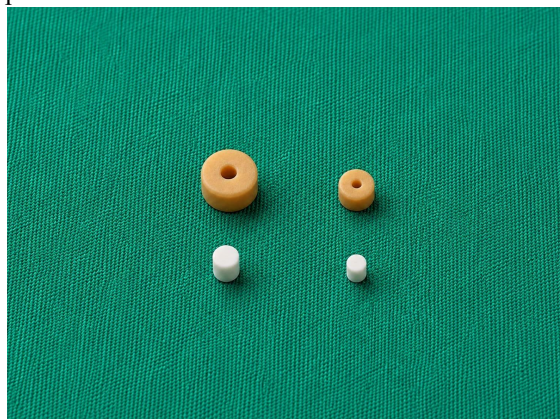


Figure 1. Representative standardised 3D printed specimens and Silicone moulds used to fabricate negative replica.

Artificial aging

All specimens were aged by thermocycling for 5,000 cycles between water baths held at 5°C and 55°C, with a dwell time of 30 seconds in each bath. Thermocycling was carried out before any surface treatment so that the repair would be made on an aged rather than a freshly polymerised substrate. Thermal cycling between these two temperatures is the most widely used laboratory method for simulating the thermal stresses of the oral environment,²² and a regimen of 5,000 cycles has

been used repeatedly in studies of composite-to-composite repair.^{8,12,13}

Surface treatment

In Groups I and II, the aged surface was roughened with a standardised medium-grit diamond bur (MANI, Inc., Tokyo, Japan) in a high-speed handpiece (NSK, Nakanishi Inc., Kanuma, Tochigi, Japan) under water cooling by giving 5 strokes back and forth on each sample for 10 seconds.

In Groups III and IV, the surface was air-abraded with Air abrasion unit (AquaCare, Velopex International, London, UK) using 50- μ m aluminium oxide particles at a pressure of 2.5 bar, from a working distance of 10 mm, for 10 seconds.

After mechanical treatment, every specimen was cleaned with 37% phosphoric acid for 20 seconds, rinsed thoroughly with water and air-dried. This sequence follows the repair protocol described by Ugurlu et al., in which phosphoric acid was applied after mechanical conditioning to clean the aged composite surface.²³ On a composite substrate, phosphoric acid does not etch in the way it etches enamel; its role is mainly to remove debris and contaminants left by roughening.²⁴ Because the step was identical in all four groups, it did not confound the comparison of interest.

Adhesive application

In Groups I and III, Clearfil SE Bond was applied according to the manufacturer's instructions. The primer was applied and allowed to react for 20 seconds before being gently air-dried for 5 seconds, after which the bonding resin was applied, air-thinned and light-cured for 10 seconds. In Groups II and IV, G-Premio Bond was applied according to the manufacturer's instructions, active application for 10 seconds, dried with air for 5 seconds and light-cured for 10 seconds. All adhesive procedures were carried out by a single operator.

Repair composite application

A standardised silicone mould with an internal diameter of 1 mm and a height of 2 mm was positioned on the centre of the bonded surface. Fresh nanohybrid composite of Tetric N-Ceram was placed into the mould and light-cured in incremental pattern. The mould was then removed carefully, light curing was done for 20 more seconds to obtain adequate polymerization. The repaired specimens were stored in distilled water at 37°C for 24 hours until testing.

Microshear bond strength testing

For testing, each composite block was seated in a custom-fabricated cold-cure acrylic resin mould that held it securely and allowed reproducible positioning in the testing machine.

Each specimen, held in its acrylic mould, was mounted in a universal testing machine (ACME, India). A loading blade was positioned parallel to, and as close as possible to, the repair interface so that

eccentric loading was kept to a minimum and the applied stress was concentrated at the interface (Figure 2). Shear load was applied at a crosshead speed of 1 mm/min until the repair cylinder debonded, and the maximum load at failure was recorded in newtons (N).



Figure 2. Microshear bond strength test set-up. The specimen is secured in the fixture of the universal testing machine and the loading blade is aligned against the repair cylinder immediately adjacent to the adhesive interface.

Because the repair cylinder had a diameter of 1 mm (radius, $r = 0.5$ mm), the bonded area (A) was:

$$A = \pi r^2 = 3.1416 \times (0.5 \text{ mm})^2 = 0.785 \text{ mm}^2$$

Microshear bond strength was calculated for each specimen as the maximum load at failure divided by the cross-sectional area:

$$\mu\text{SBS (MPa)} = \text{Maximum load at failure (N)} / \text{Cross-sectional area (mm}^2\text{)} = F / 0.785$$

Failure mode analysis

After testing, the debonded surfaces were examined under a stereomicroscope under 20x magnification. Each failure was classified as adhesive when it ran entirely along the repair interface, cohesive when it occurred wholly within the aged substrate or the repair composite, and mixed when the fracture surface showed a combination of interfacial and cohesive features (Figure 5).

Statistical analysis

Data were analysed using statistical software IBM SPSS Statistics for Windows, Version 29.0 (IBM Corp., Armonk, NY, USA). Microshear bond strength values are presented as mean $\pm$ standard deviation (SD). The assumptions of normality and homogeneity of variance were checked before parametric testing. One-way ANOVA was used to

compare the four groups. Two-way ANOVA, with surface treatment and adhesive system as fixed factors, was used to test the main effect of each factor and their interaction. Failure-mode data were summarised as frequencies and percentages. Statistical significance was set at $p < 0.05$.

Results

Microshear bond strength

All 80 specimens were tested. The mean μSBS values of the four groups are presented in Table 3 and Figure 3. Group II (diamond bur + G-Premio Bond) recorded the highest mean value, 14.39 ± 1.18 MPa, followed by Group I (diamond bur + Clearfil SE Bond) at 13.14 ± 1.30 MPa and Group IV (air abrasion + G-Premio Bond) at 11.42 ± 0.80 MPa. Group III (air abrasion + Clearfil SE Bond) had the lowest mean value, 9.24 ± 0.78 MPa. One-way ANOVA showed a statistically significant difference among the four groups ($F = 92.098$, $p < 0.001$).

Table 3. Repair microshear bond strength (MPa) of the experimental groups

Group	Surface treatment + adhesive	n	Mean $\pm$ SD (MPa)	Rank
Group I	Diamond bur + Clearfil SE Bond	20	13.14 ± 1.30	2
Group II	Diamond bur + G-Premio Bond	20	14.39 ± 1.18	1
Group III	Air abrasion + Clearfil SE Bond	20	9.24 ± 0.78	4
Group IV	Air abrasion + G-Premio Bond	20	11.42 ± 0.80	3

One-way ANOVA: $F = 92.098$, $p < 0.001$. SD, standard deviation. Rank 1 indicates the highest mean value.

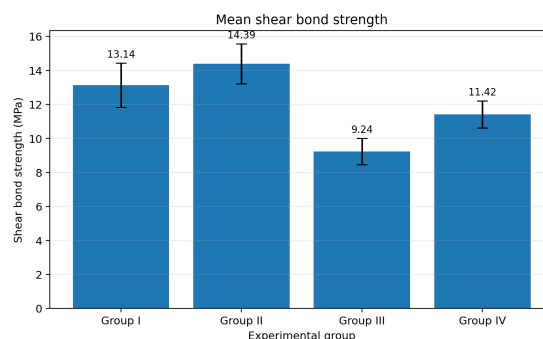


Figure 3. Mean repair microshear bond strength (MPa) of the four experimental groups. Error bars represent standard deviation. Group I, diamond bur + Clearfil SE Bond; Group II, diamond bur + G-Premio Bond; Group III, air abrasion + Clearfil SE Bond; Group IV, air abrasion + G-Premio Bond.

The results of the two-way ANOVA are given in Table 4. Surface treatment had the strongest

influence on repair strength ($F = 217.985$, $p < 0.001$). Taken together, the two diamond-bur groups averaged 13.77 MPa against 10.33 MPa for the two air-abrasion groups. The adhesive system also had a significant effect ($F = 54.314$, $p < 0.001$), with the G-Premio Bond groups averaging 12.91 MPa and the Clearfil SE Bond groups 11.19 MPa. The interaction between surface treatment and adhesive system was also statistically significant ($F = 3.996$, $p = 0.0492$). In practical terms, G-Premio Bond showed improved μ SBS to Clearfil SE Bond by 1.25 MPa on diamond-bur roughened surfaces but by 2.18 MPa on air-abraded surfaces, so the advantage of the universal adhesive depended on how the surface had been prepared. All three null hypotheses were therefore rejected. Variability was also lower in the air-abraded groups (SD 0.78–0.80 MPa) than in the bur-roughened groups (SD 1.18–1.30 MPa).

Table 4. Two-way ANOVA for the effects of surface treatment and adhesive system on repair μ SBS

Source of variation	Comparison	F value	p value
Surface treatment	Diamond-bur roughening vs Aluminium oxide air abrasion	217.985	< 0.001*
Adhesive system	Clearfil SE Bond vs G-Premio Bond	54.314	< 0.001*
Surface treatment $\times$ adhesive system	Whether the effect of one factor changes with the level of the other	3.996	0.0492*

*Statistically significant at $p < 0.05$. μ SBS, microshear bond strength; ANOVA, analysis of variance.

Failure mode analysis

The distribution of failure modes is shown in Table 5 and Figure 4, and representative stereomicroscopic images of each mode appear in Figure 5. Mixed failure was the most common pattern in Group II (12 of 20, 60%), Group IV (11 of 20, 55%) and Group III (10 of 20, 50%). Group I behaved differently: 12 of its 20 specimens (60%) failed adhesively at the repair interface, six (30%) showed mixed failure and two (10%) failed cohesively. Cohesive failure was uncommon in every group, ranging from 10% to 15%. Across the whole sample, 39 specimens (48.8%) showed mixed failure, 31 (38.8%) adhesive failure and 10 (12.5%) cohesive failure. Failure-mode data were analysed descriptively.

Table 5. Distribution of failure modes, n (%)

Group	n	Adhesive	Mixed	Cohesive	Predominant mode
Group I	20	12 (60%)	6 (30%)	2 (10%)	Adhesive
Group II	20	5 (25%)	12 (60%)	3 (15%)	Mixed
Group III	20	8 (40%)	10 (50%)	2 (10%)	Mixed
Group IV	20	6 (30%)	11 (55%)	3 (15%)	Mixed
Total	80	31 (38.8%)	39 (48.8%)	10 (12.5%)	Mixed

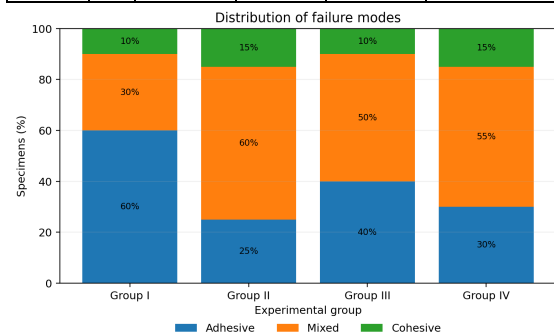


Figure 4. Percentage distribution of adhesive, mixed and cohesive failure modes in the four experimental groups.



Figure 5. Representative stereomicroscopic images of debonded specimens. (A) Adhesive failure: a clean fracture along the repair interface with no composite remaining on the substrate. (B) Mixed failure: interfacial failure combined with small fragments of retained composite. (C) Cohesive failure: fracture running within the composite material, leaving a band of fractured composite on the surface.

Discussion

Both the mechanical treatment and the adhesive changed the strength of the repair, and they did not act independently of one another. Roughening with a diamond bur gave consistently higher values than air abrasion with 50- μ m alumina, G-Premio Bond gave higher values than Clearfil SE Bond on either surface, and the gain from using the universal adhesive was larger on air-abraded composite than on bur-roughened composite. The combination of

diamond bur and G-Premio Bond reached 14.39 MPa, while air abrasion with Clearfil SE Bond managed only 9.24 MPa, a difference of more than 5 MPa produced solely by the choice of repair protocol on an identical substrate.

Effect of surface treatment

Surface treatment accounted for the largest share of the variance, with an F value roughly four times that of the adhesive system. This agrees with the general view that mechanical roughening is the non-negotiable first step of a composite repair,^{6,23} and with the network meta-analysis by Hadilou et al., in which protocols built on diamond bur roughening ranked among the most effective for long-term repair strength of aged methacrylate composites.¹⁶ Ugurlu et al. likewise found that both bur roughening and alumina air abrasion improved repair bond strength of aged nanohybrid and bulk-fill composites compared with untreated surfaces.²³ Why the bur outperformed air abrasion on this substrate probably has to do with depth. A diamond bur removes the outermost, most degraded layer of the aged composite and cuts through to material that has been less affected by water sorption and leaching, and it leaves a pattern of grooves that offers macro- as well as micromechanical retention. Air abrasion at 2.5 bar for 10 seconds, by contrast, roughens the surface without removing much of it. On a nanohybrid composite, whose fillers are small and closely packed, the resulting relief is shallow, and part of the degraded surface layer may survive underneath it. The grit of the bur has been investigated as a variable in its own right,¹¹ which reinforces the point that the amount and pattern of surface removal matter as much as the roughening method in name. The lower standard deviations in the air-abraded groups suggest that particle abrasion produces a more reproducible surface, even if a weaker one, while the bur, being operator-guided, introduces more specimen-to-specimen variation.

Not every study has come down on the side of the bur. Binhasan et al. recently found that air abrasion gave the highest microtensile repair strength on aged Tetric EvoCeram, ahead of diamond bur roughening,²⁵ and Aquino et al. reported that a diamond bur followed by adhesive alone was among the weakest protocols for aged bulk-fill composite unless silane was added.²⁶ Almutairi et al. found their diamond-abrasion group inferior to silica coating and carbide burs,¹⁵ but their diamond treatment was simulated with 600-grit silicon carbide paper, which leaves a far smoother surface than a clinical diamond bur and is not directly comparable with the bur used here. Such disagreements are expected once the bonding substrate, bur grit, blasting pressure and duration, use of silane, test geometry and aging regimen are all allowed to vary. They echo the conclusion of Loomans et al. that the best repair technique depends on the composite being repaired,¹⁴ and they argue for

caution in generalising the present ranking beyond aged nanohybrid composite and the parameters used here.

Effect of the adhesive system

The superiority of G-Premio Bond over Clearfil SE Bond may seem surprising, given the latter's reputation as a gold-standard self-etch adhesive.^{17,18} That reputation, however, rests largely on its interaction with dentin and enamel. The 10-MDP in Clearfil SE Bond forms stable ionic bonds with the calcium of hydroxyapatite, but an aged composite surface offers no hydroxyapatite; its bonding substrate is a highly cross-linked resin matrix and exposed glass fillers. On such a surface, the wetting behaviour and viscosity of the adhesive probably matter more than its capacity for chemical interaction with tooth mineral. G-Premio Bond is acetone-based and is dried under strong air pressure to a thin film, which should favour penetration into fine surface irregularities. Clearfil SE Bond places a water-containing primer on a relatively hydrophobic aged substrate and then covers it with a thicker, more viscous hydrophobic resin, which may not flow as completely into the base of fine irregularities.

This reasoning also fits the interaction observed in the present study. On a bur-roughened surface, with its wider grooves, both adhesives could probably flow adequately into the retentive features, and the difference between them was modest (1.25 MPa). On the finer, shallower relief left by air abrasion, the lower-viscosity universal adhesive held a clearer advantage (2.18 MPa). A similar dependence of universal adhesive performance on prior roughening was reported by Yilmaz et al., who found that repair strength with G-Premio Bond fell significantly short of the positive control when the aged composite was left untreated.¹⁹ Yin et al. reported that universal adhesives improved repair bond strength regardless of etching mode, and that the result varied with the particular adhesive used,²⁰ while Altinci et al. found universal-adhesive repairs of nanohybrid composites to be comparatively stable under thermocycling.²¹

Neither adhesive in this study was preceded by a separate silane. Nagano et al. found that applying an adhesive improved repair strength on water-aged nanofilled composites, whereas adding a silane coupling agent did not.⁷ In the same vein, Michelotti et al. showed that a separate silanisation step before a universal adhesive did not raise composite-to-composite repair strength after different mechanical pretreatments,²⁷ and Ugurlu et al. observed no benefit from silane in either nanohybrid or bulk-fill substrates.²³ Other authors disagree, recommending silane particularly after bur roughening,^{16,26} so whether a separate silane would have altered the ranking seen here remains an open question.

Failure modes

The failure-mode data add a useful qualification to the strength values. In Groups II, III and IV, most

specimens failed in a mixed pattern, which implies that at least part of the fracture path ran through the composite and that the interface was not simply the weakest link. Group I was the exception, with 60% of its failures adhesive despite a mean strength second only to Group II. The most likely explanation is that the combination of deep bur grooves and a two-step adhesive with a relatively thick hydrophobic layer left some areas of the interface incompletely wetted, so that when the bond failed it did so cleanly along the adhesive layer. Group III, by contrast, had the lowest strength but a predominantly mixed pattern. A plausible reading is that fracture in these specimens partly originated in a superficial substrate layer that air abrasion had disturbed but not removed.

Bond strength and failure mode do not map onto each other one-to-one, and this should be expected. In shear tests the stress at the interface is far from uniform, and the magnitude and location of stress concentrations depend on specimen geometry, loading distance and the stiffness of the components.²⁸ Cohesive failures in shear testing in particular can reflect this stress distribution rather than a bond that is genuinely stronger than the material.²⁸ The consistent message across groups is still worth noting: the combination that produced the highest strength (Group II) also produced the lowest proportion of purely adhesive failures (25%), which was also the pattern Almutairi et al. saw, with adhesive failure concentrated in their weaker groups.¹⁵

Methodological considerations

The microshear configuration was chosen because the small bonded area (0.785 mm²) reduces the number of interfacial defects included in each test and allows many specimens to be prepared from a standard substrate.²⁸ Printing the master model and duplicating it in addition silicone kept the substrate geometry identical across all 80 specimens, and the custom acrylic holder ensured that each specimen sat in the same position relative to the loading blade. Thermocycling for 5,000 cycles represents a moderate aging challenge; Gale and Darvell's review of thermal cycling protocols is still the reference most often cited for cycle numbers,²² and this regimen has been used in several earlier repair studies.^{8,12,13} Absolute bond-strength values should not be compared directly with those from microtensile or macroshear studies, because test geometry has a strong influence on the numbers obtained.²⁸

Clinical relevance

For the clinician, the practical message is reassuring. Diamond burs are present in every operatory, whereas intraoral air-abrasion units are not, and in this study the bur was not only adequate but superior on aged nanohybrid composite. Pairing the bur with a one-bottle universal adhesive gave the strongest repair and also involves fewer steps than a two-step

self-etch system, an advantage when the repair margin crosses composite, enamel and dentin in the same preparation. If air abrasion is used, the choice of adhesive appears to matter more, and a low-viscosity universal adhesive is preferable to a two-step self-etch system.

Limitations

Several limitations apply. This was an in vitro study, and thermocycling cannot reproduce the combined mechanical, chemical and biological challenges of the oral environment. Only one nanohybrid composite was tested, and the same material was used for both substrate and repair, so the results may not extend to other formulations or to repairs made with a different composite. No untreated negative control and no cohesive-strength positive control were included, which means the results show how the four protocols compare with one another rather than how close any of them came to the intrinsic strength of the material. Surface roughness and topography were not measured by profilometry or scanning electron microscopy, so the explanations offered for the difference between bur and air abrasion remain inferential. Bond strength was measured at a single time point after repair, without post-repair aging or cyclic loading, even though intraoral repairs are loaded cyclically, and Stape et al. have examined the fatigue strength of universal adhesives in composite repair for exactly this reason.²⁹ Finally, failure modes were analysed descriptively. Studies that add surface characterisation, post-repair aging, fatigue loading and additional composite formulations would help establish how durable these differences are.

Conclusions

Within the limitations of this in vitro study, both the mechanical surface treatment and the adhesive system significantly influenced the repair microshear bond strength of aged nanohybrid composite resin, and the two factors interacted. Diamond bur roughening produced higher repair bond strength than 50- μ m aluminium oxide air abrasion. G-Premio Bond produced higher repair bond strength than Clearfil SE Bond with both surface treatments, and its advantage was greater on air-abraded surfaces. Diamond bur roughening combined with G-Premio Bond gave the highest mean value (14.39 $\pm$ 1.18 MPa), and air abrasion combined with Clearfil SE Bond gave the lowest (9.24 $\pm$ 0.78 MPa). Mixed failure predominated in all groups except the diamond bur and Clearfil SE Bond group, in which adhesive failure was most frequent. For chairside repair of an aged nanohybrid composite, diamond bur roughening followed by a universal adhesive appears to be a simple and effective protocol.

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Disclosures

Human subjects: This in vitro study did not involve human participants or human tissue. **Ethics approval:** The Institutional Ethics Committee, Government Dental College and Hospital, Jamnagar, issued approval 107/02/2026. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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