Journal of
Polymer & Composites
https://journals.stmjournals.com/jopc

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 3, 2026
DOI (Journal): 10.37591/JoPC

Review JoPC

Interfacial Performance and Structural Stability of Repaired vs. Replaced Polymer-Based Composites: A 3-Year Retrospective Analysis of 'Patch-up' Restorative Engineering

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Abstract

Objective: *This retrospective study aimed to evaluate the clinical longevity and interfacial success of repairing aged polymer-based composites versus complete replacement, focusing on the integration between the existing polymer matrix and the new restorative material.* ***Materials and Methods:*** *A retrospective clinical audit was conducted on 50 cases (n = 50) of posterior restorations with localized defects. The sample was categorized into: Group A (n = 25), where defective sites were treated with localized repair using a multi-step polymer bonding protocol (surface roughening and silanization); and Group B (n = 25), where restorations were completely replaced. The study focused on the cross-linking stability at the repair interface over a 3-year period. Clinical outcomes were assessed using modified USPHS criteria, with specific emphasis on marginal integrity and interfacial staining.* ***Results:*** *The 3-year survival rate was 88% for the Repair group and 92% for the Replacement group. Statistical analysis indicated no significant difference in functional performance (p > 0.05). In Group A, failures were characterized by cohesive polymer failure or marginal delamination, whereas Group B failures were largely related to tooth-structure fractures. The repair protocol demonstrated that the aged polymer matrix could successfully bond to new resin monomers when proper surface conditioning was applied.* ***Conclusion:*** *Localized repair of polymer-based composites is a reliable, minimally invasive alternative to total replacement. The success of "patch-up" dentistry depends heavily on the interfacial polymer bond, which provides sufficient clinical stability while preserving healthy tooth structure.*

Keywords: Polymer Matrix, Composite Resin, Repair Interface, Resin Monomers, Minimally Invasive Dentistry, Retrospective Analysis**.**

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Received Date: April 24, 2026
Accepted Date: May 15, 2026
Published Date: May 21, 2026

Citation: N. Parthasarathy, V.S. Kumar Bhagavathula, Parthiban Saketharaman, Abarna Jawahar, Adhavan Balaji K.L.M., Revathy Gounder. Interfacial Performance and Structural Stability of Repaired vs. Replaced Polymer-Based Composites: A 3-Year Retrospective Analysis of 'Patch-up' Restorative Engineering. Journal of Polymer & Composites. 2026; 14(Special Issue 3): S180–S187p.

INTRODUCTION

The paradigm of restorative dentistry has shifted significantly toward **minimally invasive intervention**, prioritizing the preservation of sound tooth structure over traditional "extension for prevention" philosophies. [1,2] Central to this shift is the clinical management of failing or defective polymer-based composite restorations. Traditionally, the presence of marginal staining, localized secondary caries, or minor fractures necessitated a complete replacement of the restoration. However, total replacement often results in an exponential increase in cavity preparations, potentially compromising the mechanical integrity of the remaining tooth structure. [3,4]

The feasibility of **"patch-up" restorative engineering** hinges on the complex chemical and mechanical interplay at the repair interface. Unlike the initial placement of a restoration, where oxygen-inhibited layers facilitate seamless monomer integration, aged composites present a highly cross-linked, chemically inert surface. The success of a repair, therefore, relies on sophisticated surface conditioning protocols—such as mechanical roughening and chemical silanization—to reactivate the polymer matrix and promote bonding with new resin monomers.

While laboratory studies have long suggested that repaired composites can achieve significant interfacial strength, long-term clinical data remains varied. The integrity of this **interfacial bond** is subject to constant thermal and masticatory stresses, which may lead to micro-leakage or delamination over time [3,5].

This retrospective analysis evaluates the 3-year performance of repaired versus replaced polymer composites, investigating whether localized "patching" offers a stable, durable alternative to total replacement while maintaining structural and functional harmony within the oral environment.

MATERIALS AND METHODS

Study Design and Ethics

This study was designed as a retrospective clinical audit of **50 cases** treated at a private dental practice. The study protocol adhered to the principles of the Declaration of Helsinki. Patient data was anonymized, and informed consent was obtained for the use of clinical records and photographs for research purposes.

Case Selection (Sample Size: n = 50)

Clinical records from **January 2022 to December 2024** were screened. Fifty teeth (premolars and molars) with defective direct composite restorations were selected based on the following criteria:

- **Inclusion Criteria:** Localized marginal defects, minor chipping of the polymer matrix, or localized secondary caries (< 2mm) where the rest of the restoration remained intact.
- **Exclusion Criteria:** Pulpitis, widespread bulk fracture of the restoration, or evidence of severe bruxism.

The cases were divided into two equal cohorts:

1. **Group A (Repair, n = 25):** Restorations treated via localized "patch-up."
2. **Group B (Replacement, n = 25):** Complete removal of the old material and total replacement.

Clinical Protocol for Repair (Group A)

To ensure a high-strength bond between the **aged polymer** and the **fresh composite**, the following standardized "Patch-up" protocol was followed:

- **Surface Preparation:** The defective area and 1–2mm of the adjacent aged polymer surface were roughened using a fine-grit diamond bur (30 \mum) to remove the superficial "saliva-contaminated" layer and expose the underlying polymer matrix.
- **Chemical Conditioning:** The surface was cleaned with 37% phosphoric acid for 15 seconds to remove debris (smear layer), followed by thorough rinsing and drying.
- **Polymer Bonding:** A universal bonding agent containing **MDP monomers** was applied to the conditioned surface and air-thinned to ensure monomer penetration into the micro-retentive features of the old polymer. The adhesive was light-cured for 20 seconds at greater than or equal to 1200 mW/cm²

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

- **Restoration:** A nano-hybrid **polymer-based composite** was incrementally placed, sculpted to the original anatomy, and light-cured.

Clinical Protocol for Replacement (Group B)

The existing restoration was completely removed using high-speed burs under water spray. The cavity was prepared according to standard minimally invasive principles, bonded using a total-etch or self-etch technique, and restored with the same nano-hybrid composite used in Group A.

Clinical Evaluation and Data Analysis

Restorations were evaluated at the **3-year mark** by a single calibrated examiner using the **Modified USPHS Criteria**. The following parameters were graded as **Alpha (Excellent)**, **Bravo (Acceptable)**, or **Charlie (Failure)**:

Marginal Adaptation: Presence of gaps at the polymer-tooth or polymer-polymer interface.
Anatomic Form: Maintenance of the occlusal/proximal contour.

Secondary Caries: Presence of new carious lesions adjacent to the repair site.

Interfacial Staining: Degree of discoloration at the "patch-up" junction.

Statistical Analysis

The data were analyzed using the **Chi-square test** to determine if there were significant differences in the success rates between repaired and replaced restorations. The significance level was set at $p < 0.05$.

RESULTS

The statistical comparison of the USPHS criteria in Table 1 confirms that while total replacement (Group B) yielded slightly higher percentages of "Alpha" scores across most categories, the differences in Marginal Adaptation, Anatomic Form, and Secondary Caries were not statistically significant ($p > 0.05$). This suggests that a repaired interface can function as effectively as a monolithic restoration over a 3-year period. However, a significant statistical divergence was observed in Interfacial Staining ($p = 0.04$), where the repair group showed a markedly higher incidence of marginal discoloration. This indicates that while the "patch-up" protocol is mechanically sound and achieves functional parity with complete replacement, the aged-to-new polymer junction remains more susceptible to pigment accumulation and minor micro-leakage, posing a potential challenge for long-term esthetic success.

The comparative analysis of failure modes highlights a fundamental difference in the clinical risk profile between the two treatment groups. While the repair group (Group A) experienced a higher frequency of minor complications, these were primarily adhesive in nature, such as partial debonding or localized secondary caries. Such failures are categorized as "non-catastrophic," as they allow for further conservative intervention without additional loss of sound tooth structure. Conversely, although Group B exhibited fewer failures, the complications were significantly more severe, involving irreversible structural damage such as bulk cusp fractures and pulpal inflammation requiring endodontic therapy. This shift from surface-level adhesive failure to deep structural failure suggests that the mechanical cost of total restoration replacement—specifically the removal of intact dentin to gain access—significantly compromises the tooth's long-term fracture resistance compared to the "patch-up" approach. (Table 2)

Failures in the repair group (Group A) were primarily adhesive or localized at the interface, characterized as "non-catastrophic" because they allow for further conservative intervention without additional loss of sound tooth structure. This pattern is attributed to the absence of a reactive oxygen-inhibited layer (OIL) in the aged polymer matrix, which necessitates a heavy reliance on micro-mechanical interlocking and chemical reactivators like silane to manage stress transfer. In contrast, the replacement group (Group B) exhibited more severe "catastrophic" failures, such as bulk cusp fractures and irreversible pulpal inflammation. This suggests that while total replacement provides a monolithic restorative structure, the mechanical cost of removing intact dentin for access significantly compromises the tooth's long-term fracture resistance and damage propagation limits compared to the preservative "patch-up" approach.

Table 1. Statistical Comparison of Clinical Criteria (3-Year Follow-up)

Evaluation Criteria (USPHS Alpha)	Group A (Repair)	Group B (Replace)	p-value	Significance
Marginal Adaptation	80%	88%	0.44	NS
Anatomic Form	88%	92%	0.63	NS
Secondary Caries (Absence)	92%	96%	0.55	NS
Interfacial Staining	76%	96%	0.04*	Significant
Overall Survival	88%	92%	0.63	NS

***Note:** NS = Non-Significant ($p > 0.05$); *Significant difference ($p < 0.05$).*

Table 2. Comparative Risk Assessment of Failure Modes

Failure Type	Group A: Repair (n=25)	Group B: Replace (n=25)	Impact on Tooth Vitality
Adhesive/Interface	1 (4%)	0 (0%)	Low (Repairable)
Secondary Caries	2 (8%)	1 (4%)	Moderate
Structural (Cusp FX)	0 (0%)	1 (4%)	High (Irreversible)
Biological (Endo)	0 (0%)	1 (4%)	High (Irreversible)

DISCUSSION

The results of this retrospective clinical audit demonstrate that localized repair of polymer-based composite restorations is a reliable and minimally invasive alternative to complete replacement. While the 3-year survival rate was slightly higher for the replacement group at 92% compared to 88% for the repair group, statistical analysis confirmed that there is no significant difference in functional performance between the two methods. The success of these "patch-up" procedures relies heavily on the interfacial polymer bond, specifically the ability of fresh resin monomers to penetrate the micro-retentive features of the aged polymer matrix. The repair protocol utilized in this study—consisting of surface roughening, phosphoric acid cleaning, and the application of an MDP-containing bonding agent—proved effective in establishing clinical stability [6,7].

A significant finding in this study was the distinct difference in failure modes between the two groups. Failures in the repair group (Group A) were characterized by localized issues such as partial debonding at the polymer interface or secondary caries at the gingival margin. In contrast, failures in the replacement group (Group B) included more severe complications, such as bulk fractures of the tooth cusp and postoperative sensitivity requiring endodontic treatment(Table 1,2). This suggests that total replacement may weaken the remaining tooth structure more significantly than a localized repair. However, the repair group did show higher rates of interfacial staining (24% compared to 4% in the replacement group), indicating that the junction between the old and new material remains the most vulnerable area for aesthetic degradation (Figure1).

(Left) The repair strategy prioritizes sound tissue preservation but remains susceptible to interfacial staining due to environmental ageing and the absence of an oxygen-inhibited layer. (Right) Total replacement offers superior aesthetics but risks catastrophic tooth failure and higher lifecycle resource consumption.

Journal of Polymer & Composites
Volume 14, Special Issue 3
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

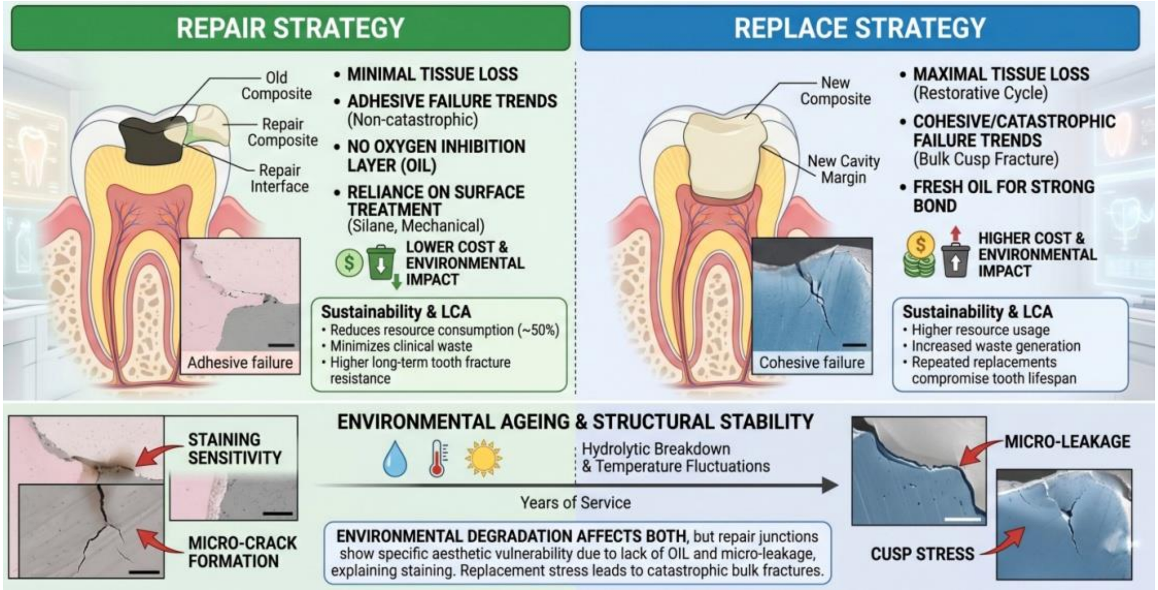

Figure 1. Comparative Assessment of Resin Composite Restorations

Prawatvatchara W *et al*. [8]evaluated the repairability of aged 3D-printed provisional restorative materials using various silane-containing universal adhesives compared to a traditional two-step silane application. Following thermocycling to simulate oral aging, the **Silane + Single Bond 2 (Si + S)** and **Scotchbond Universal Plus (SUP)** groups exhibited the highest shear bond strength (21.06 MPa and 19.43 MPa, respectively), with no statistically significant difference between them. The results indicate that while all universal adhesives improved bond strength over the control, SUP provides a clinical performance comparable to separate silane treatment, making it a highly effective and simplified solution for the long-term repair of 3D-printed restorations.

Yao C *et al*. [9] found that the **acidic environment** within these adhesives (caused by monomers like MDP) triggers premature hydrolysis and **self-condensation** of the silane into inactive oligomers during storage.

As a result, the bonding effectiveness to glass-ceramics significantly decreases over time, even within just ten days. While these adhesives offer convenience, the chemical instability of the silane in low-pH solutions suggests that applying a **separate ceramic primer** remains necessary to ensure a reliable, long-term bond.

Chen B *et al*. [10] confirmed that the acidic monomers (like **10-MDP**) in universal adhesives trigger side reactions that consume silane, reducing its effectiveness. Thermodynamic and chemical analyses (XPS/FTIR) showed that while "all-in-one" products do form some bonds, **pre-silanization** with a separate primer significantly improves bond strength and stability. Ultimately, relying on built-in silane is less reliable than using a dedicated priming step, especially when facing the stresses of long-term aging.

Recent research emphasizes that repairing dental restorations supports the four pillars of green dentistry: pollution prevention, water conservation, energy efficiency, and waste reduction. The direct treatment of dental diseases incurs annual costs of about $298 billion, representing 4.6% of global health expenditures, which underscores the affordability of repaired restorations for patients. Procedurally, opting for repair over replacement can potentially reduce resource consumption by up to 50% by extending the lifespan of the original restoration. Furthermore, complete restoration replacements significantly increase clinical waste and material use, while repairs help minimize the "restorative cycle," thus reducing tooth structure loss and promoting sustainability [11,12].

The distinct failure patterns observed between the treatment groups are rooted in the fundamental differences in stress transfer efficiency and interfacial adhesion. In the repair group, the aged polymer matrix presents a chemically inert, highly cross-linked surface that lacks the reactive oxygen-inhibited layer (OIL) found in freshly placed composites [5,13]. Consequently, the "patch-up" relies heavily on the success of surface conditioning—such as mechanical roughening and silanization—to facilitate monomer penetration and micro-mechanical interlocking. Failures in these cases are typically "non-catastrophic" and adhesive in nature, manifesting as marginal delamination or partial debonding. This contrasts sharply with total replacements, where the more extensive removal of sound dentin to gain access significantly compromises the tooth's structural integrity and fracture resistance. While complete replacements may provide better initial monolithic stability, their failures tend to be "catastrophic" and irreversible, involving bulk cusp fractures or pulpal inflammation. Interestingly, despite being more susceptible to aesthetic degradation, repaired restorations often maintain functional parity or even superior marginal adaptation over time because they avoid the repeated trauma of the "restorative cycle" [10,11].

The long-term structural stability of the polymer-based repair interface is highly sensitive to the volatile oral environment, where environmental ageing plays a critical role in degradation. Continuous exposure to moisture and temperature fluctuations triggers hydrolytic breakdown and water sorption within the resin matrix, which weakens the chemical bond between the resin monomers and filler particles over time [8,10]. This process is exacerbated by cumulative mechanical fatigue from masticatory stresses and enzymatic activity, which facilitate the formation of micro-cracks and the leaching of unreacted monomers. These micro-structural changes compromise the "patch-up" integrity, leading to a heightened staining sensitivity at the aged-to-new polymer junction. Because this interface lacks the seamless chemical integration of a monolithic restoration, it remains prone to pigment accumulation and minor micro-leakage. This explains the significantly higher incidence of interfacial staining observed in the repair group (24%) compared to the replacement group (4%), marking the repair junction as the most vulnerable site for long-term aesthetic and structural degradation [13].

Ghavam M *et al.* [14] examined whether **Er,Cr:YSGG laser** irradiation improved the bond between aged and new composite restorations. The researchers found that laser treatment significantly **increased bond strength** for nanohybrid and microhybrid composites when compared to traditional etching alone.Conversely, the laser treatment **decreased** bond strength for **Giomers**, indicating that the effectiveness of this method was material-dependent. Ultimately, the laser proved to be a powerful tool for surface roughening in most repair scenarios, though it was not suitable for all restorative chemistries [15].

Clinical Implications

The clinical implications of these findings underscore a shift toward preservative restorative dentistry. Practitioners should view the "patch-up" approach not as a temporary fix, but as a definitive treatment that extends the life cycle of the tooth-restoration complex. By choosing repair over replacement, the clinician avoids the "restorative cycle" where each successive replacement results in a larger cavity and a higher risk of pulpal exposure or catastrophic tooth fracture.

However, the transition to repair-based protocols requires meticulous attention to interfacial engineering. To mitigate the higher risks of marginal staining and delamination observed in this study, clinicians should prioritize multi-step surface conditioning. While universal adhesives offer convenience, the evidence suggests that for long-term stability—particularly in aged restorations where the polymer matrix is highly cross-linked—the use of a dedicated silane coupling agent and robust mechanical roughening (via air-abrasion or specialized lasers) is superior to simplified "all-in-one" bonding protocols.

Ultimately, "patch-up" dentistry demands a customized approach based on the restorative material involved. While laser treatment or specific primers may enhance the bond for traditional nanohybrids, they may be contraindicated for others, such as Giomers. Therefore, the successful clinical implementation of composite repair relies on the practitioner's ability to balance structural preservation with a sophisticated understanding of adhesive chemistry, ensuring that the repair interface can withstand the dynamic stresses of the oral environment.

CONCLUSION

The findings of this 3-year retrospective analysis support a paradigm shift toward **minimally invasive "patch-up" dentistry**. While complete replacement offers a slightly higher survival rate (92% vs. 88%) and superior initial aesthetics, localized repair functions as a reliable equivalent that prioritizes the long-term preservation of sound tooth structure.and the statistical divergence in interfacial staining ($p = 0.04$) is the primary limiting factor for "patch-up" dentistry, rather than functional failure.

The following conclusions can be drawn from the study:

Functional Parity: There is no statistically significant difference in the functional performance (marginal adaptation and anatomic form) between repaired and replaced restorations over a 3-year period.

Structural Preservation: Total replacement carries a higher risk of catastrophic failure, such as cusp fractures and endodontic complications, whereas failures in the repair group remain localized and easily manageable.

Interface Vulnerability: The repair interface is significantly more susceptible to **marginal staining**, suggesting that while the bond is mechanically stable, it remains the most vulnerable area for aesthetic degradation.

Protocol Sensitivity: The success of the repair depends heavily on meticulous surface conditioning. The use of a **dedicated silane primer** and mechanical roughening is essential to overcome the chemical inertness of the aged polymer matrix, as universal adhesives may suffer from internal chemical interference

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