ORIGINAL ARTICLE

Biomedica - Official Journal of University of Health Sciences, Lahore, Pakistan
Volume 41(1):10-15
https://doi.org/10.24911/BioMedica/5-1196

Comparative analysis of various surface treatment techniques on the shear bond strength of repaired dental composite materials

Hira Asghar[1], Hammad Hassan[2*], Sana Akram[3], Muhammad Asif Shahzad[4], Ayma Syed[5], Zenab Yasir[6]

ABSTRACT

Background and Objective: Repairing composite restorations is a conservative alternative to replacement, and bond strength is influenced by both the composite type and surface treatment. This study compared the shear bond strength of microhybrid and bulk-fill composites repaired with bulk-fill composite using different surface treatment protocols.

Methods: This experimental study, conducted from July 2023 to February 2024, included 120 samples: 60 microhybrid composites and 60 bulk-fill composites. The samples were divided into a control group with no further treatment and an experimental group with additional surface treatments. The samples were prepared in Teflon molds, cured, aged in deionized water, and exposed to thermal cycling as per ISO standard/TR 11405(2003). The surface treatments included roughening, application of a universal adhesive (iBOND Universal), sandblasting with alumina, and a silane coupling agent (Bis-Silane, BISCO Inc.). The repair composites were applied and cured, followed by shear bond strength testing using a universal testing machine.

Results: Specific post hoc comparisons revealed that control groups generally exhibited the lowest bond strengths, with varying mean values: 11.98 ± 3.83, 23.01 ± 7.46, and 12.90 ± 3.03 MPa for different controls. Conversely, specimens treated with bulk-fill material consistently showed higher shear bond strength, especially those undergoing sandblasting, which recorded the highest bond strengths among all the groups tested ($p < 0.01$). Additionally, the failure analysis under a stereo light microscope revealed a transition in rupture types from "adhesive interface" to "cohesive in composite" in aged specimens, after thermal cycling, indicating a reduction in the cohesive strength over time.

Conclusion: Sandblasting notably improved the repair effectiveness, emphasizing the importance of surface preparation in dental composite repairs. These findings underscore the need for careful selection of surface treatment techniques to optimize repair outcomes in dental restorations.

Keywords: Composite resins, dental materials, dental restoration, shear strength.

Received: 07 September 2024 **Revised 1:** 12 November 2024 **Revised 2:** 28 December 2024 **Accepted:** 26 January 2025
Correspondence to: Hammad Hassan
*Assistant Professor, Science of Dental Materials, University of Health Sciences, Lahore, Pakistan.
Email: hammadhassanh@gmail.com
Full list of author information is available at the end of the article.

Introduction

Recent advancements in dental composite resin formulations and enhanced clinical techniques have significantly increased the use of resin-based composites for both anterior and posterior restorative procedures, establishing them as indispensable options in modern dentistry.[1,2] However, while these materials perform satisfactorily over the long term, their effectiveness depends heavily on maintenance protocols aimed at addressing issues such as discolorations, microleakage, and partial fractures of the restorations.[3]

The yearly failure rate of composite resin restorations varies from 1% to 5% in permanent teeth, and from 1.7% to 12.9% in primary teeth. Given these figures, dealing with defective restorations can generally be approached in two ways: complete replacement or repair.[4] While replacement often entails further damage to healthy dental tissues due to the necessity for larger cavity preparations, opting for repair is more advantageous. Repair methods not only conserve more of the original dental structure but also offer a cost-effective solution for public health systems. Nevertheless, effective interaction between two composite layers depends on an oxygen-inhibited layer that has not fully polymerized, which facilitates the effective bonding of monomers from a newly applied composite resin.[5] Over time, the bonding ability of an aged composite resin may diminish significantly due to a reduction in the amount of unreacted monomers available for bonding.[6]

Researchers have indicated that to achieve satisfactory bond strength in aged composite restorations, additional surface treatments are essential. Several surface treatment methods for the original composite are recommended, such as mechanical roughening, acid etching, employing low viscosity bonding agents, applying "flowable" composites, and using silane. These techniques enhance the adhesion properties between the existing composite material and the new application, ensuring the durability and structural integrity of the restoration.[7]

Silane surface treatment effectively promotes mechanical interlocking, surface wetting, and chemical bonding in composite repairs by facilitating the formation of siloxane bonds from the silanol groups. Concurrently, the methacrylate groups form covalent bonds with the resin during polymerization.[8] Successful restoration repair not only requires appropriate surface treatment of the aged resin but also careful selection of an adhesive system and restorative material. Although numerous studies have explored various repair strategies, definitive guidelines for the repair process remain unestablished.[9]

Additionally, advancements in composite material technology have led to the development of low-shrinkage composites with enhanced depth of cure, differentiated from conventional composites by specialized resin monomers, photoinitiators, and fillers. These bulk-fill resin composites, which can be applied in increments of up to 4-5 mm, ensure more effective polymerization.[10]

Despite these technological innovations, identifying the type of composite resin used during aesthetic restoration repair remains a clinical challenge, as clinicians often cannot determine the specific type of fractured or chipped composite at the time of repair.[8] Commercial brands vary in their compositions, and the type of resin primarily influences the bond strength of repairs. It is also a common practice to use composite resins with different compositions during restoration procedures.[11] Furthermore, despite extensive research, there is no universally accepted repair method for various composite resins, highlighting the need to evaluate the effectiveness of different repair protocols.[12]

Previous studies have predominantly concentrated on the bond strength between identical composite types. However, this research investigates the repair of two distinct types of composites, traditional methacrylate-based composites and the newly developed bulk-fill composites, utilizing a variety of surface treatment options. The repairs were performed using a universal adhesive augmented with a layer of silane coupling agent and sandblasting, as opposed to the multiple conventional adhesives used in earlier studies. This methodology was designed to improve the clinical relevance and durability of composite-based restorations, thereby providing a more time-efficient solution.

This study aimed to evaluate and compare the shear bond strength of microhybrid and bulk-fill composite specimens repaired with bulk-fill composites using various surface treatment protocols (surface roughening, sandblasting, and silane application followed by adhesive). It also assesses the effect of thermal aging through thermocycling on the durability of the repair bond.

Methods

This experimental study was conducted from August 2023 to February 2024, after receiving ethical approval from the Institutional Review Board of Azra Naheed Dental College, Lahore, Pakistan.

A total of 120 samples were included and equally divided between Experimental Group A (microhybrid composite, Te-Econom Plus, shade A2) and Experimental Group B (bulk-fill composite, Tetric N-Ceram bulk-fill, shade A). All the samples were prepared using Teflon molds (5 mm in diameter and 5 mm in depth) to ensure consistent dimensions and surface uniformity.

A standard formula for comparing the means between two independent groups was used to determine the sample size.[13] The formula incorporated the expected difference in means (effect size), SDs of the groups, and desired levels of power and significance. With the SDs $\sigma 1 = 1.05$ and $\sigma 2 = 2.1$, effect size = 2.2, a power of $Z1-\beta = 0.84$, and a significance level corresponding to a critical value $z1-\alpha/2 = 1.96$, resulted in five samples per group.[13] However, to increase the statistical power of the study, precision, and generalizability, the sample size was increased to 60 per group, making a total sample size of 120. A non-probability purposive sampling method was utilized to select the samples.

Microhybrid samples were filled incrementally and light-cured for 40 seconds per increment, while bulk-fill samples were placed and cured in a single increment under the same conditions. Light polymerization was performed using an LED curing unit (Elipar, 3M ESPE) with an intensity of 800-1,000 mW/cm^2 at 2 mm. After curing, all specimens were stored in deionized water at 37°C for 24 hours to simulate intraoral conditions. The samples were then subjected to artificial aging through 500 thermal cycles between 5°C and 55°C, with a dwell time of 20 s, in accordance with the ISO standard TR 11405:2003.

All samples included in the study were required to be properly fabricated using standardized Teflon molds, fully polymerized, and exhibit uniform dimensions with smooth, defect-free surfaces. Samples were excluded if they displayed any visible defects such as fractures, cracks, incomplete polymerization, surface irregularities, or dimensional inconsistencies.

Following aging, the bonding surfaces of all samples were mechanically roughened in a uniform direction using 320-grit silicon carbide paper and then rinsed and air-dried. Each experimental group (microhybrid and bulk-fill) was further divided into three subgroups (n = 20), based on the surface treatment protocol applied prior to repair. In subgroups A1 and B1, a universal adhesive (*iBOND Universal*, Kulzer) was applied immediately after roughening. In subgroups A2 and B2, samples were first sandblasted with 30-micron alumina particles and then coated with a universal adhesive. In subgroups A3 and B3, a silane coupling agent (*Bis-Silane*, BISCO Inc.) was applied before the universal adhesive (Table 1). A Tetric N-Ceram bulk-fill composite was used as the repair material after each surface treatment.

The shear bond strength testing was conducted using a universal testing machine at a crosshead speed of 0.5 mm/min. A chisel-like apparatus was used to apply a shear force at the interface between the aged and repaired composite layers until failure occurred. The maximum force required to cause debonding was recorded in megapascals (MPa).[8]

After the mechanical testing, the fractured surfaces were examined under a stereo light microscope at 40× magnification to determine the mode of failure. Failures were classified into three categories: adhesive (failure at the bond interface), cohesive (failure within the composite), or mixed (a combination of both).

Statistical analysis

Data were analyzed using the International Business Machines (IBM) Statistical Package for Social Sciences Statistics version 20 (IBM Corp., Armonk, New York). Data distribution was assessed using the Kolmogorov-Smirnov test. Quantitative data, such as shear bond strength, were presented as mean ± SD. ANOVA followed by post hoc Tukey's test was used to compare the mean shear bond strength across the different treatment groups, and a p-value ≤ 0.05 was considered statistically significant.

Results

The failure mode patterns of the specimens from the experimental groups, analyzed using a stereo light microscope at 40X magnification following the shear bond strength tests, are shown in Table 2. Adhesive failures were the most frequent in Experimental Group A (microhybrid), followed by mixed and cohesive failures.

In contrast, Experimental Group B (bulk-fill) showed a higher frequency of mixed and cohesive failures, with adhesive failure being the least common (Table 2).

Table 1. *Experimental groups and surface treatment subgroups.*

Group	Subgroup	Surface treatment	Sample size
Experimental Group A (Microhybrid composite)	A1	Surface roughening + Universal Adhesive	20
	A2	Surface roughening + Sandblasting (30 µm alumina) + Universal Adhesive	20
	A3	Surface roughening + Silane (Bis-Silane, BISCO Inc.) + Universal Adhesive	20
Experimental Group B (Bulk-fill composite)	B1	Surface roughening + Universal Adhesive	20
	B2	Surface roughening + Sandblasting (30 µm alumina) + Universal Adhesive	20
	B3	Surface roughening + Silane (Bis-Silane, BISCO Inc.) + Universal Adhesive	20

Table 2. *Failure mode patterns across surface-treated Microhybrid and bulk-fill composite groups.*

Group	Subgroup	Composite type	Adhesive n (%)	Cohesive n (%)	Mixed n (%)
Experimental Group A	A1	Microhybrid (n = 10)	4 (40.0)	3 (30.0)	3 (30.0)
	A2	Microhybrid (n = 10)	3 (30.0)	2 (20.0)	5 (50.0)
	A3	Microhybrid (n = 10)	4 (40.0)	4 (40.0)	2 (20.0)
	Total A	Microhybrid (n = 30)	11 (36.7)	9 (30.0)	10 (33.3)
Experimental Group B	B1	Bulk-fill (n = 10)	3 (30.0)	4 (40.0)	3 (30.0)
	B2	Bulk-fill (n = 10)	2 (20.0)	3 (30.0)	5 (50.0)
	B3	Bulk-fill (n = 10)	2 (20.0)	3 (30.0)	5 (50.0)
	Total B	Bulk-fill (n = 30)	7 (23.3)	10 (33.3)	13 (43.3)

Table 3. *Overall comparison between microhybrid and bulk-fill groups.*

Experimental groups	Shear bond strength (MPa) Mean ± SD	*F*	*p*-value
Group A - microhybrid composite	15.96 ± 6.42	4.11	0.045
Group B - bulk-fill composite	19.68 ± 8.66		

Table 4. *Intra-group comparison of surface treatment protocols using the Tukey Post Hoc Test.*

Experimental groups		Shear bond strength (MPa) Mean ± SD	Comparison	*p*-value
Group A - microhybrid composite	A1	11.98 ± 3.83	A1 *vs.* A2	0.004
	A2	23.01 ± 7.46	A1 *vs.* A3	0.761
	A3	12.90 ± 3.03	A2 *vs.* A3	0.006
Group B - bulk-fill composite	B1	15.23 ± 4.59	B1 *vs.* B2	0.009
	B2	29.15 ± 11.24	B1 *vs.* B3	0.874
	B3	14.67 ± 2.34	B2 *vs.* B3	0.012

Table 5. *Intergroup comparison of corresponding surface treatments between Microhybrid and Bulk-fill composites.*

Subgroup comparison	Surface treatment	*F*-value	*p*-value
A1 *vs.* B1	Surface roughening + Adhesive	2.18	0.134
A2 *vs.* B2	Sandblasting + Adhesive	3.94	0.041
A3 *vs.* B3	Silane + Adhesive	1.23	0.273

The overall comparison of the shear bond strength between the microhybrid and bulk-fill composite groups revealed statistically significant differences among the subgroups (Table 3). Bulk-fill composites (Group B) showed higher mean shear bond strengths than microhybrid composites.

Within the microhybrid Group A (group A), subgroup A2 showed significantly higher bond strength than both A1 ($p = 0.004$) and A3 ($p = 0.006$). No significant differences were observed between A1 and A3 ($p = 0.761$). However, in the bulk-fill group (Group B), B2 also showed a significantly higher bond strength than B1 ($p = 0.009$) and B3 ($p = 0.012$), while B1 and B3 were not significantly different ($p = 0.874$) (Table 4).

Among the corresponding surface treatments, A2 and B2 showed statistical significance ($p = 0.041$), indicating that bulk-fill composites benefit more from sandblasting than microhybrid composites (Table 5).

Discussion

The current study evaluated the shear bond strength of bulk-fill composite samples repaired using a bulk-fill hybrid and various surface treatment techniques, compared to samples made with microhybrid composites. The findings demonstrated that sandblasting followed by the application of a universal adhesive significantly enhanced the bond strength of both composite types. This treatment provides high bond strength owing to increased surface roughness, which aids in mechanical interlocking between the old and new composite materials.[3,13] These results confirm that mechanical surface roughening through alumina-based sandblasting provides superior micromechanical interlocking, which is critical for durable bonding between aged and new composites.[14]

Surface treatment with lasers, such as Er,Cr:YSGG, also shows promise. However, its effectiveness varies and is generally less than that of traditional mechanical methods, such as sandblasting, but can be beneficial when combined with silane and a bonding agent.[15] The aged bulk-fill resin composites treatment with methods such as Al_2O_3 sand-blasting combined with laser treatment results in higher repair bond strength, emphasizing the importance of choosing appropriate surface treatments for aged composites to ensure effective repair.[1] In the current study, the highest repair strength resulted from the combination of sandblasting with adhesive, whereas the majority of failures were cohesive or mixed in Group B (bulk-fill). However, Group A showed a higher percentage of adhesive failures, particularly in subgroups that did not undergo sandblasting, implying a weaker bond at the repair interface. These observations reinforce that surface conditioning significantly influences failure patterns and repair integrity. The literature reported that surfaces treated with Al_2O_3 sandblasting and laser in aged bulk-fill resin composites exhibited higher repair bond strength values.[16]

Although silane is widely acknowledged for improving the composite bond strength through chemical coupling and enhanced wettability, its isolated application in this study (A3 and B3) did not yield significantly better results.[17] This may be due to the material composition, interaction with the universal adhesive used, or absence of mechanical roughening.[1] While the literature suggests that silane can enhance bonding when used properly or incorporated into adhesives, the current findings indicate that mechanical treatment alone, especially sandblasting, is more influential in improving bond strength than silane application alone.[18,19] The findings of the present study indicate that the microshear bond strength varies depending on the type of composite resin used and that surface roughening generally enhances the bond strength of these materials.[10]

Literature has shown that aging significantly diminished the repair strength of both the bulk-fill and traditional composite resins; however, enhancing with 10% hydrofluoric acid and bonding with resin adhesive effectively increased the repair strength, especially in bulk-fill restorative composites.[10,17,20] This study also confirms that bulk-fill composites generally show superior repair performance compared to microhybrid composites when treated using the same protocol, potentially because of their improved depth of cure and optimized filler/resin matrix. These differences may account for the significantly higher repair bond strength observed in the B2 subgroup.[21]

Fonseca and their team studied four surface treatments, ranging from simple macro-mechanical roughening to more complex methods that included chemical and resin-based enhancements and reported that basic roughening alone did not significantly improve bond strength. However, a combination of roughening and intermediate resin application notably improved the bond strength, particularly in nano-filled resins, and maintained this strength even after stress tests such as thermocycling. The most effective treatment combined roughening, sandblasting, a chemical agent, and resin, which significantly improved the strength of all tested resins.[3,22,23]

Overall, these findings highlight the importance of selecting appropriate surface treatments when performing composite repair, particularly in aged restorations. Among the tested protocols, sandblasting followed by universal adhesive application was the most effective. This combination not only improved the bond strength significantly but also altered the failure mode toward more desirable cohesive patterns, suggesting enhanced durability and clinical reliability.

Limitations of the Study

This study was conducted under controlled *in vitro* conditions, which may not fully replicate the complex oral environment, including factors such as saliva, occlusal forces, and long-term thermal and mechanical stress. Additionally, only one universal adhesive and specific composite material brand were used, which may limit the generalizability of the results. Future studies should explore a broader range of adhesive systems, incorporate long-term aging protocols, and evaluate the repair performance under simulated clinical conditions to better reflect real-world outcomes. Investigating additional surface treatments, such as laser conditioning and plasma etching, could also offer valuable insights.

Conclusion

The present study concluded that surface treatment significantly influences the shear bond strength of repaired composite restorations. Sandblasting notably improved the repair effectiveness, emphasizing the importance of surface preparation in dental composite repairs. These findings underscore the need for careful selection of surface treatment techniques, including combining mechanical and chemical conditioning, to optimize repair outcomes in dental restorations**.** Thus, incorporating sandblasting into routine repair protocols may enhance the durability and longevity of composite restorations.

Acknowledgement

The authors are thankful to the Dean of Dentistry and Head of Science of Dental Materials Department at Azra Naheed Dental College, Superior University, Lahore, for their support during the execution of this research work.

List of Abbreviations

IBM	International Business Machines
ISO	International Organization for Standardization
LED	Light Emitting Diode
MPa	Megapascal

Conflict of interest

None to declare.

Grant support and financial disclosure

None to disclose.

Ethical approval

Ethical approval was obtained from the Institutional Review Board of Azra Naheed Dental College Lahore vide Letter No. ANDC/RAC2023/20 dated: 02-08-2023.

Authors' contributions

HA: Conception and design, Revision of the manuscript, Statistical analysis, Methodology, Investigation, Data curation, Draft preparation.

HH: Conception and design, Analysis and interpretation of the data, Drafting of the article, Investigation, Data curation, Draft preparation.

SA: Conception and design, Revision of the article, Drafting of the manuscript, Data curation.

MAS: Collection and assembly of data, Drafting of the manuscript, Data analysis, Interpretation of results.

AS, ZY: Literature search, Revision of the manuscript, Data interpretation.

ALL AUTHORS: Approval and responsibility for the final version of the manuscript to be published.

Authors' Details

Hira Asghar[1], Hammad Hassan[2], Sana Akram[3], Muhammad Asif Shahzad[4], Ayma Syed[5], Zenab Yasir[6]

1. Associate Professor, Science of Dental Materials, Azra Naheed Dental College, Superior University, Lahore, Pakistan
2. Assistant Professor, Science of Dental Materials, University of Health Sciences, Lahore, Pakistan
3. Assistant Professor, Science of Dental Materials, Azra Naheed Dental College, Superior University, Lahore, Pakistan
4. Professor, Department of Oral & Maxillofacial Surgery, Azra Naheed Dental College. Superior University, Lahore, Pakistan
5. Head, Department of Community Dentistry, Azra Naheed Dental College. Superior University, Lahore, Pakistan

6. Associate Professor, Science of Dental Materials, Akhtar Saeed Medical and Dental College, Lahore, Pakistan

References

1. Şişmanoğlu S, Gürcan AT, Yıldırım-Bilmez Z, Gümüştaş B. Efficacy of different surface treatments and universal adhesives on the microtensile bond strength of bulk-fill composite repair. J Adhes Sci Technol. 2020;34(10):1115–27. https://doi.org/10.1080/01694243.2019.1698202
2. Nazar A, Munir Mb, Rafiq A, Khalid S, Hassan H. Success of veneers with indirect resin composite. Pak J Med Health Sci. 2021;15(12):3619–22. https://doi.org/10.53350/pjmhs2115123619
3. Stape TH, Tulkki O, Salim IA, Jamal KN, Mutluay MM, Tezvergil-Mutluay A. Composite repair: on the fatigue strength of universal adhesives. Dent Mater. 2022;38(2):231–41. https://doi.org/10.1016/j.dental.2021.12.003
4. Silva CLD, Scherer MM, Mendes LT, Casagrande L, Leitune VCB, Lenzi TL. Does use of silane-containing universal adhesive eliminate the need for silane application in direct composite repair? Braz Oral Res. 2020;34:e045. https://doi.org/10.1590/1807-3107bor-2020.vol34.0045
5. Ferreto-Gutiérrez I, Hernández-Mata A. Mathematical-physical description of the oxygen-inhibited layer (OIL) in nanofilled dental polymers. Odovtos Int J Dent Sci. 2024;26(1):65–75. https://doi.org/10.15517/ijds.2023.56092
6. Bulut A, Bala O, Akgül S. The effect of different treatment protocols on shear bond strength in resin composite restoration repair. BMC Oral Health. 2024;24(1):1279. https://doi.org/10.1186/s12903-024-04918-y
7. Çakir NN, Demirbuga S, Balkaya H, Karadaş M. Bonding performance of universal adhesives on composite repairs, with or without silane application. J Conserv Dent. 2018;21(3):263–8. https://doi.org/10.15171/joddd.2016.002
8. Sarahneh O, Günal-Abduljalil B. The effect of silane and universal adhesives on the micro-shear bond strength of current resin-matrix ceramics. J Adv Prosthodont. 2021;13(5):292. https://doi.org/10.4047/jap.2021.13.5.292
9. Oglakci B, Arhun N. The shear bond strength of repaired high-viscosity bulk-fill resin composites with different adhesive systems and resin composite types. J Adhes Sci Technol. 2019;33(14):1584–97. https://doi.org/10.4103/tdj.tdj_47_22
10. Ayar MK, Guven ME, Burduroglu HD, Erdemir F. Repair of aged bulk-fill composite with posterior composite: effect of different surface treatments. J Esthet Restor Dent. 2019;31(3):246–52. https://doi.org/10.1111/jerd.12391
11. Karabekiroglu KN, Al-Haj Husain N, Özcan M. Evaluation of multimode adhesion promoters with functional monomers without and with silica-coating for resin composite repair. J Adhes Sci Technol. 2023;37(8):1485–500. https://doi.org/10.1080/01694243.2022.2080424
12. Almutairi MA, Salama FS, Alzeghaibi LY, Albalawi SW, Alhawsawi BZ. Surface treatments on repair bond strength of aged resin composites. J Int Soc Prev Community Dent. 2022;12(4):449–55. https://doi.org/10.4103/jispcd.JISPCD_99_22
13. Bilgrami A, Maqsood A, Alam MK, Ahmed N, Mustafa M, Alqahtani AR, et al. Evaluation of shear bond strength between resin composites and conventional glass ionomer cement in class II restorative technique—an *in vitro* study. Materials. 2022;15(12):4293. http://dx.doi.org/10.3390/ma15124293
14. Aquino C, Mathias C, Barreto SC, Cavalcanti A, Marchi G, Mathias P. Repair bond strength and leakage of non-aged and aged bulk-fill composite. Oral Health Prev Dent. 2020;18(1):783–91. http://dx.doi.org/10.3290/j.ohpd.a45082
15. Dogan E, Cevval Ozkocak BB. The efficacy of Er, Cr: YSGG laser and contemporary universal adhesive systems on composite resin repair bond strength: an *in vitro* study. Odontology. 2024;112(4):1197–208. https://doi.org/10.1007/s10266-024-00932-2
16. Didangelou P, Dionysopoulos D, Papadopoulos C, Strakas D, Mourouzis P, Tolidis K. Evaluation of repair bond strength of a dental CAD/CAM resin composite after surface treatment with two Er, Cr: YSGG laser protocols following artificial aging. J Mech Behav Biomed Mater. 2023;146:106101. https://doi.org/10.1016/j.jmbbm.2023.106101
17. Ömeroğlu MK, Çam M, Doğruer I, Kaynar ZB. The effect of different surface treatments and adhesive systems on shear bond strength in universal nanohybrid composite resin repair. BMC Oral Health. 2025;25(1):1–10. https://doi.org/10.1186/s12903-025-05807-8
18. Ugurlu M, Al-Haj Husain N, Özcan M. Repair of bulk-fill and nanohybrid resin composites: effect of surface conditioning, adhesive promoters, and long-term aging. Mater. 2022;15(13):4688. https://doi.org/10.3390/ma15134688
19. Ahlholm P, Staxrud F, Sipilä K, Vallittu P. Repair bond strength of bulk-fill composites: influence of different primers and direction of debonding stress. Biomater Investig Dent. 2023;10(1):2258924. https://doi.org/10.1080/26415275.2023.2258924
20. Akgül S, Kedici Alp C, Bala O. Repair potential of a bulk-fill resin composite: effect of different surface-treatment protocols. Eur J Oral Sci. 2021;129(6):e12814. https://doi.org/10.1111/eos.12814
21. El-Tahtawi M, Laithy A, Soliman Z, El-Askary F. Repair durability of a water-aged microfine hybrid restorative resin composite: a nano-leakage study. Egypt Dent J. 2021;67(1):871–81. https://doi.org/10.21608/edj.2020.50498.1351
22. Hatırlı H, Tonga G, Boyraz Ş. Water sorption, solubility and color stability of different bulk-fill restorative materials. Cumhuriyet Dent J. 2022;25(4):293–301. https://doi.org/10.7126/cumudj.1116211
23. Khoroushi M, Bahrani MM, Zandian A, Fathpour K. Repair strength of dimethacrylate-based composites resins: effect of sandblasting, adhesive bonding, and thermocycling. Dent Res J. 2023;20(1):46. https://doi.org/10.4103/1735-3327.374803