

Evaluation of the adhesive strength of PMMA using resin cement and preheated resin: An *in vitro*-Study

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Abstract

Objective: To evaluate the bond strength of polymethyl methacrylate (PMMA) when cemented using two different strategies: light-cured resin cement and preheated composite resin.

Method: Sixteen PMMA sheets ($n = 8$ per group) were prepared and standardized in size. The samples were randomly divided into two groups: (1) cementation with light-curing resin cement and (2) cementation with composite resin preheated to 55–60 °C. Each group was further divided into two subgroups: 1) Sandblasting: the PMMA surfaces were sandblasted with 50 μm aluminum oxide for 5 seconds; and 2) Phosphoric acid: phosphoric acid was applied to the PMMA surface for 15 seconds. Subsequently, 4 resin microtubes were cemented onto each sheet; these were fabricated from Tygon tubing and composite resin, then light-cured using a high-power Valo Grand LED lamp. After 24 hours of storage in distilled water, the specimens were subjected to a micro-shear test on a universal testing machine, with values recorded in MPa at a speed of 0.5 mm/min.

Results: Based on this study, it is concluded that the protocol consisting of resin cement combined with PMMA sandblasting is established as the safest, most effective, and most predictable option for indirect restorations.

Keywords: PMMA, Resin Cement, Preheated Composite Resin, Adhesive Strength, *In vitro*-study.

Introduction

Polymethyl methacrylate (PMMA) is a polymeric material widely used in dentistry, particularly for the fabrication of temporary restorations and prostheses. Its selection is justified by characteristics such as acceptable aesthetics, low density, ease of handling, versatility in clinical applications, and, most importantly, its favorable cost-benefit ratio, making it an affordable option for patients who cannot undergo definitive treatments immediately. (Díez-Pascual, 2022; Zafar, 2020) (Juntavee *et al.*, 2023)^[8, 15, 26]

Despite its advantages, PMMA has limitations related to its longevity and clinical performance. One of the main challenges is ensuring adequate adhesion of the material to the tooth structure, an essential aspect even in temporary restorations, as it influences the stability, marginal seal, and durability of the treatment. (Dawood Jadaan *et al.*, 2025) (Galant *et al.*, 2024)^[7, 13]

Various cementing agents have been used for this purpose. Resin cements, available in chemically cured, dual-cure, or light-cured versions, are notable for their hardness, low solubility in the oral environment, and ability to form micromechanical bonds with enamel and dentin. (Elkaffass *et al.*, 2020^[9]; Lousan do Nascimento Poubel *et al.*, 2022; Silva *et al.*, 2023)^[4, 16]. On the other hand, the use of preheated composite resins has been proposed as a viable alternative, since the increase in temperature reduces viscosity, improves flow, and decreases film thickness, which can result in better marginal adaptation and greater resistance to wear. (Marcondes *et al.*, 2021)^[17]

A fundamental aspect in the evaluation of cementation systems is the selection of a reliable method to measure adhesion between materials. In dentistry, microtensile and microshear mechanical tests have been widely used to analyze adhesive strength at the interface between the restoration and the tooth structure, whether on enamel or

dentin. These tests, recognized for several years, constitute a reliable and standardized benchmark for evaluating the performance of different adhesive materials. In this regard, the use of a universal testing machine allows for the collection of objective and reproducible data regarding the adhesive behavior of PMMA when combined with different cementing agents.

In this context, it is worth investigating which of these cementation strategies—resin cement or preheated composite resin—offers better adhesive performance with PMMA. In this way, even though it is a temporary material, greater stability and clinical longevity could be ensured for the benefit of the patient.

Methodology

This was an experimental, *in vitro* study with a comparative design. The factor under investigation was the type of cementing agent used to bond PMMA, employing two different strategies: light-cured resin cement and preheated composite resin. The outcome measure was micro-shear bond strength (μSBS).

Samples Preparation

Sixteen PMMA plates ($n = 8$ per group) were fabricated with standardized dimensions of 10 mm \times 10 mm and a thickness of 1 mm (Grangeiro *et al.*, 2023)^[14] from Upcera brand PMMA blocks using a DWX-52Di milling machine. We fabricated 64 resin tubes measuring \varnothing 0.8 mm \times 2 mm in height (4 microtubes per test specimen) using Tygon tubing and composite resin. First, we cut the Tygon tubing to a length of 2 mm, then packed the Filtek Z250 composite resin (3M ESPE) into the tube, and finally light-cured it with a Valo Grand LED curing light. We then removed the resin tube using a 15C scalpel.

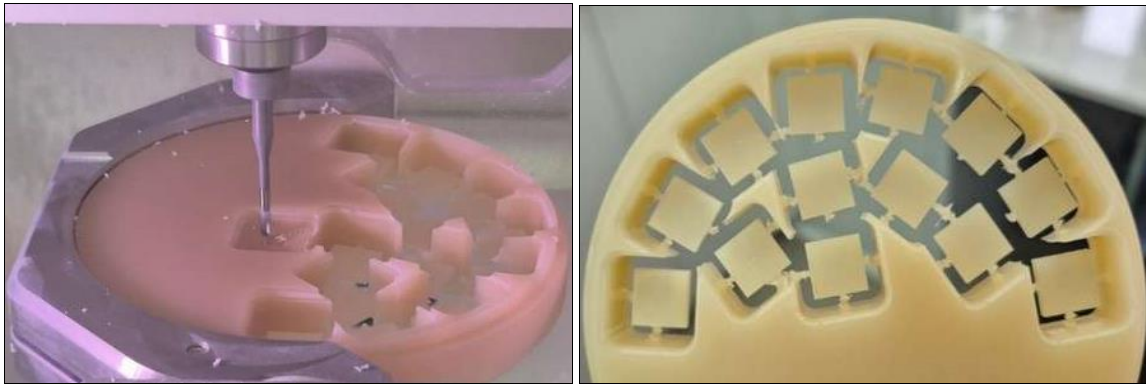


Fig 1: Milling samples with the DWX-52Di and producing PMMA sheets



Fig 2: Fabrication of resin tubes 2 mm high and 0.8 mm in diameter using Tygon

Cementation Protocol

The samples were randomly divided into two groups

1 Cement Group (Resin Cement): The PMMA surfaces were treated with 3M Relyx Ultimate light-curing resin cement.

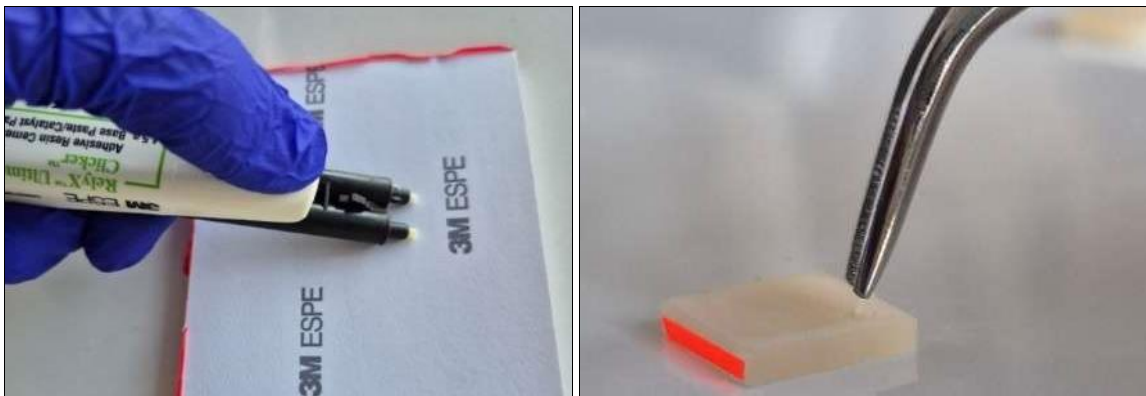


Fig 3: Cementation of a resin tube onto a sandblasted PMMA surface using resin cement

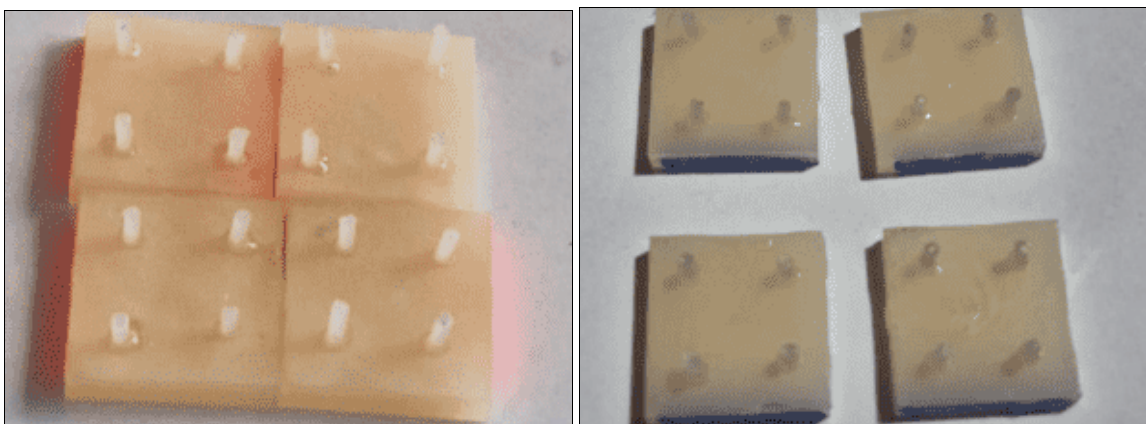


Fig 4: Groups G1 (orange) and G2 (blue)

2 Resin Group – (Preheated composite resin): The PMMA surfaces were coated with Filtek Z350 XT composite resin, which had been preheated to 55°C in an Ena Heat heater from the Micerium group.



Fig 5: Ena Heat resin heater, Micerium group

Each group will then be randomly divided into two subgroups:

Subgroup 1: sandblasting: sandblasting was performed using 50-micron aluminum oxide for 5 seconds at a distance of 10 mm.

Subgroup 2: phosphoric acid: the PMMA surfaces were treated with phosphoric acid for 20 seconds and then washed with pressurized water

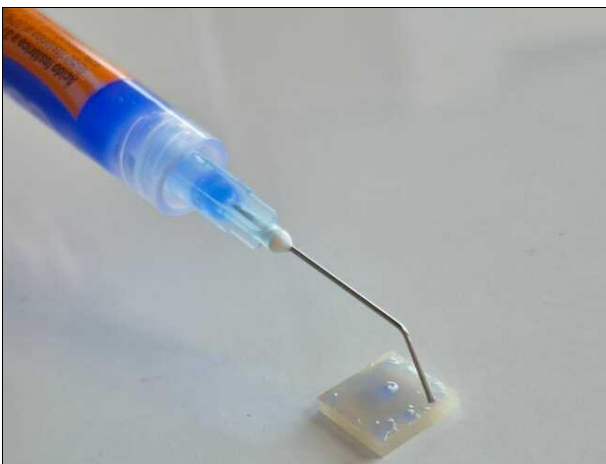


Fig 6: Application of Condac FGM 37% Orthophosphoric Acid,



Fig 7: Light-curing with the Valo Grand LED curing light, Ultradent



Fig 8: Groups G3 (red) and G4 (white)

The samples were affixed to clear acrylic cylinders to facilitate handling, and were then stored in containers until they were tested.

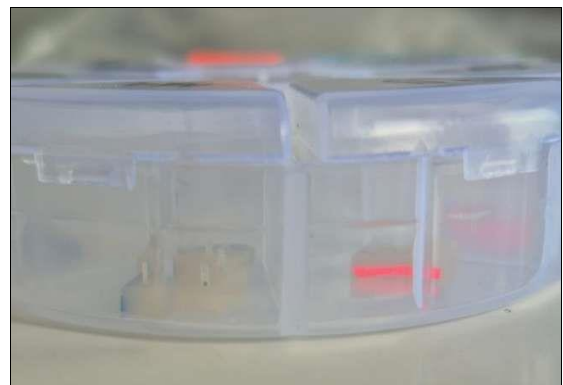


Fig 9: Samples stored in a container

Adhesive Strength Test

After 24 hours of storage in distilled water at 37°C, the samples were subjected to a microshear test on a Muvet universal testing machine, with the load applied at a rate of 0.5 mm/min until adhesive failure occurred. The strength values were recorded in MPa. The tensile strength of the specimens was determined by the ratio of the load recorded at the moment of fracture (kgf) to the area of the specimen at the fracture plane (cm²), expressed in MPa. These values will be referred to as bond strength (BS) for each specimen evaluated.

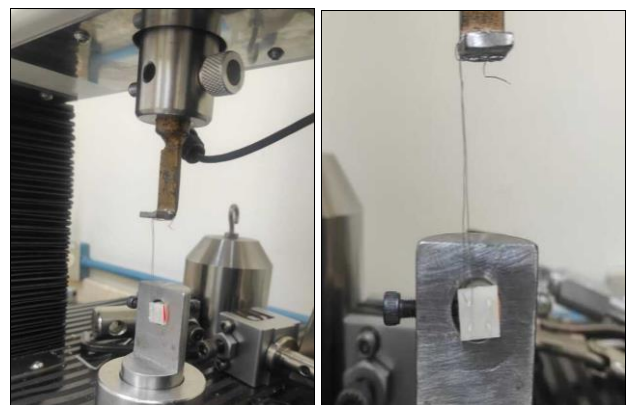


Fig 10: Muvet Universal Testing Machine (Dynamometer)

The experimental design included four groups, each initially consisting of 16 specimens, corresponding to the combinations of bonding agent and surface treatment. During the microshear test, it was observed that some specimens did not yield measurable force values due to detachments that occurred before or immediately upon the application of the load.

These events were recorded as pre-test failures, as they reflect an absence of functional bonding between the PMMA and the cementing material. In the preheated composite resin with sandblasting group, two failures were recorded, while in the preheated composite resin with phosphoric acid group, all specimens exhibited immediate detachment. Consequently, of the 64 specimens initially

planned, only 46 yielded continuous values of bond strength in MPa.

It is important to note that these data were not excluded due to methodological errors but rather constitute a result inherent to the adhesive behavior of the evaluated combinations. For this reason, the statistical analysis was structured by differentiating between continuous values of bond strength and categorical events of adhesive failure.

Descriptive Statistics of Adhesive Strength

Table 1 presents the main descriptive measures of adhesive strength expressed in MPa for each experimental group. Included are the number of valid specimens, the mean, the standard deviation, the median, the minimum and maximum values, as well as the 95% confidence interval of the mean.

Table 1: Descriptive statistics of adhesive strength (MPa) by group

Group	Experimental condition	n valid	Mean	Of	Median	Minimum	Maximum	IC 95%
G1	Resin-based cement + sandblasting	16	23,66	9,39	23,97	4,87	36,32	18,66 – 28,66
G2	Resin cement + phosphoric acid	16	7,21	4,29	7	1,93	20,03	4,93 – 9,50
G3	Preheated resin + sandblasting	14	2,87	1,38	2,38	1,48	6,65	2,07 – 3,67
G4	Preheated resin + phosphoric acid	0	No measurable	—	—	—	—	—

Source: Author

The descriptive statistics reveal clear differences in the magnitude of adhesive strength among the groups. Group G1 had the highest mean values and the widest range of variation, while groups G2 and G3 showed progressively lower values. In group G4, it was not possible to calculate descriptive statistics due to the complete absence of measurable values.

The variability observed within each group, reflected in the standard deviation and the range of values, suggests that adhesive behavior is not uniform and that factors associated with the experimental combination significantly influence the strength obtained.

2. Assessment of the Assumption of Normality

Before performing comparisons between groups, the assumption of normality of the available data was assessed. Table 3 presents the results of the Shapiro–Wilk test applied to the groups with continuous adhesive strength data.

Table 2: Test of normality (Shapiro–Wilk)

Group	n	W	p-rate
G1 Resin-based cement + sandblasting	16	0,942	0,376
G2 Resin cement + phosphoric acid	16	0,853	0,015
G3 Preheated resin + sandblasting	14	0,842	0,017

Source: self elaboration

The p-values indicate that, although Group G1 does not deviate significantly from normality, Groups G2 and G3 do exhibit significantly non-normal distributions. Since the comparative analysis requires that this assumption be met jointly, the use of parametric tests was ruled out.

The absence of normality in all evaluable groups justified the use of nonparametric tests, which do not depend on the shape of the distribution of the datum. Based on this methodological framework, an inferential comparison between the groups was conducted.

Inferential Comparison Between Groups

Given the failure to meet the assumption of normality and the presence of more than two independent groups, the

Kruskal–Wallis test was selected as the overall comparison method. Table 4 presents the results of the Kruskal–Wallis test applied to the groups with continuous data.

Table 3: Statistics from the Kruskal–Wallis Test

Estatistical	rate
H-statistic (Kruskal–Wallis) 32,83 Degrees of freedom (df) 2 p-value (asymptotic) <0,001 Significance level 0,05	

Source: self elaboration

Once it was verified that the data as a whole did not meet the assumption of normality, an inferential comparison between the experimental groups was performed using the Kruskal–Wallis test. This nonparametric test allows for the evaluation of whether there are statistically significant differences between more than two independent groups, based on a comparison of the ranks of the values rather than the means. Table 4.X presents the details of the mean ranks and the sum of ranks used to calculate the test statistic.

To perform the test, all bond strength values were sorted from lowest to highest and replaced by ranks. Subsequently, the mean rank for each experimental group was calculated. The resin cement with sandblasting group had the highest mean rank (34.06), indicating that it contained the highest values of adhesive strength. In contrast, the preheated composite resin with sandblasting group showed the lowest mean rank (7.32), reflecting inferior adhesive performance.

The Kruskal–Wallis (H) statistic obtained was 32.83, with 2 degrees of freedom, and a p-value less than 0.001. This result indicates that the differences observed between the groups' mean ranks are statistically significant and not attributable to chance, confirming the existence of at least one group with distinct behavior in terms of adhesive strength.

Once the existence of statistically significant overall differences between the groups was identified using the Kruskal–Wallis test, it was necessary to perform paired comparisons to determine specifically between which groups these differences occurred. For this purpose, the Mann–Whitney U test was used, a nonparametric test

suitable for comparing two independent groups when the assumption of normality is not met.

Table 4: Paired comparisons (Mann–Whitney U, adjusted p)

Comparison	n ₁	n ₂	U	Z	p-adjusted rate*
G1 vs G2	16	16	20	-4,12	< 0,001
G1 vs G3	16	14	0	-4,98	< 0,001
G2 vs G3	16	14	24	-3,28	0,001

Source: self elaboration

The Mann–Whitney U test compares the distribution of ranks between two groups, assessing whether one group tends to have higher values than the other. In the comparison between the resin-bonded cement with sandblasting group and the resin-bonded cement with phosphoric acid group, a U value of 20.0 and an adjusted p-value of less than 0.001 were obtained, indicating a statistically significant difference between the two combinations.

Similarly, the comparison between the resin-bonded cement with sandblasting group and the preheated composite resin with sandblasting group showed a U value of 0.0, indicating a complete separation between the ranks of both groups and confirming a highly significant difference. Finally, the comparison between resin-modified cement with phosphoric acid and preheated composite resin with sandblasting also showed statistically significant differences, with an adjusted p-value of 0.001.

Paired comparisons using the Mann–Whitney U test confirm that all experimental combinations with measurable data differ significantly from one another in terms of bond strength. These results allow for a clear ranking of adhesive performance among the evaluated groups, which is summarized and presented in an integrated manner in the following section of the chapter.

Discussion

The cement plays a key role in the adhesion of indirect restorations, especially when dealing with polymeric substrates such as PMMA. Comparing resin cement and preheated composite resin allows us to assess whether materials with different clinical indications offer comparable adhesive performance under controlled conditions. (Teyagirwa *et al.*, 2023) (Aravind *et al.*, 2023)^[1, 24]

In this study, specimens cemented with resin cement exhibited significantly higher bond strength values than those obtained with preheated composite resin. (Calheiros-Lobo *et al.*, 2023)^[4]

This finding is consistent with the report by Pashley *et al.*, 2011^[21], who describe that resin cements are formulated to optimize wettability, micromechanical penetration, and the formation of a more stable hybrid interface compared to conventional restorative resins. Likewise, Topdağı, 2025^[25] notes that resin cements exhibit greater adaptability to mechanically treated surfaces, which promotes more predictable adhesion.

From a scientific perspective, these results reinforce the notion that resin cements offer structural and functional advantages over composite resins used as cementing agents. This difference justifies the specific analysis of PMMA surface treatment as a factor modulating adhesion. (Topdağı, 2025)^[25].

The goal of PMMA surface treatment is to modify its topographic and energetic properties, facilitating interaction with the cementing agent. Multiple conditioning strategies have been described in the literature, with sandblasting and phosphoric acid etching being two of the most commonly evaluated techniques. (Dantagnan *et al.*, 2025)^[5]

In the present study, sandblasting of PMMA was associated with the highest values of adhesive strength when resin cement was used. This behavior can be explained by the increase in surface roughness and the generation of micromechanical interlocks, as described by Nishigawa *et al.*, 2016^[20]. In contrast, phosphoric acid etching did not produce a comparable increase in bond strength, which is consistent with studies indicating that PMMA exhibits a limited response to acid etching due to its chemical nature and low reactivity.

surface treatment (Dantagnan *et al.*, 2025) (Atalay *et al.*, 2021)^[2, 5].

These findings confirm that not all surface treatments are equally effective on polymeric materials such as PMMA. From a scientific standpoint, sandblasting emerges as a more consistent technique for promoting the adhesion, which leads to an analysis of the behavior of alternative materials, such as preheated composite resin, under these same conditions. (Dawood Jadaan *et al.*, 2025)^[7].

The use of preheated composite resin has been proposed as an alternative to resin-based cement, based on the assumption that increasing the temperature improves the material's flowability and marginal adaptation. (Porto *et al.*, 2022)^[22]. However, evidence regarding its adhesive performance on PMMA remains limited. (Zafar, 2020)^[26].

In this study, the preheated composite resin exhibited significantly lower adhesive strength values and a high frequency of pre-test failures, especially when combined with phosphoric acid. Although previous studies have shown that preheating can increase monomer conversion and reduce the material's viscosity (Daronch *et al.*, 2005) (Barbon *et al.*, 2022)^[3, 6], these benefits did not translate into effective adhesion to PMMA under the conditions evaluated.

Among the main limitations of the present study is its *in vitro* nature, which does not fully replicate actual clinical conditions. Furthermore, artificial aging protocols, such as thermal or mechanical cycling, were not included, which could influence the durability of the adhesive bond, as noted in previous studies in the field of dental adhesion (Matinlinna *et al.*, 2018)^[18].

Despite these limitations, the results obtained provide relevant evidence regarding the adhesive behavior of different material combinations. Future studies should incorporate aging conditions and complementary tests to validate and expand upon the findings presented here.

The choice of cement is one of the most critical clinical decisions in indirect restorations, as it directly influences the stability, retention, and longevity of the restoration. In polymeric materials such as PMMA, this choice takes on special importance due to the limited chemical interaction of the substrate with many conventional adhesive systems. (Muddugangadhar *et al.*, 2020)^[19]

Specimens cemented with resin cement exhibited significantly higher adhesive strength values and an absence of pre-test failures, compared to preheated composite resin. Clinically, this indicates that resin-based cement offers more stable and predictable adhesion to PMMA, which is

consistent with the findings reported by Pashley *et al.*, 2011^[21], who highlight that these cements are designed to optimize wettability and micromechanical penetration in various substrates. (Aravind *et al.*, 2023)^[1]

From a clinical perspective, these findings support the preferred use of resin cement in indirect PMMA restorations, especially in cases where the restoration will be subjected to repetitive functional loads or where reliable short- and medium-term retention is required, such as with temporary crowns during orthodontic treatment. (Dawood Jadaan *et al.*, 2025)^[7] This choice reduces the risk of early de-cementation and contributes to a more favorable clinical prognosis, leading to the consideration of PMMA surface treatment as a key complementary factor. (Aravind *et al.*, 2023)^[1]

It has been observed that PMMA surface treatment aims to improve the interaction between the substrate and the cementing agent, increasing micromechanical retention and, potentially, the durability of the adhesive bond. (Erbulak & Ergun, 2023)^[10] In clinical practice, the most commonly used methods include sandblasting and phosphoric acid etching; in this case, the study results showed that sandblasting of PMMA was associated with the highest values of adhesive strength when resin cement was used, whereas phosphoric acid etching did not produce a comparable increase.

Clinically, this can be explained by the increase in surface roughness induced by sandblasting, which generates effective micromechanical retention; therefore, these results suggest that sandblasting should be considered the surface treatment of choice for PMMA restorations when resin cements are used. (Erbulak & Ergun, 2023) (Gad *et al.*, 2022)^[10, 11]

The exclusive use of phosphoric acid may prove insufficient in clinical situations where adhesion is required, increasing the risk of early restoration loss. This finding takes on special relevance when evaluating alternative materials such as preheated composite resin, which in this study showed inferior adhesive performance and a high frequency of pre-test failures, particularly when combined with phosphoric acid. Although previous studies have reported benefits of preheating in terms of monomer conversion and clinical handling (Daronch *et al.*, 2005)^[6], these benefits did not translate into effective and stable adhesion to PMMA under the conditions evaluated.

Clinically, the high failure rate observed in this study suggests that preheated composite resin does not provide reliable adhesion to PMMA when should not be used as a cementing agent, especially without proper surface treatment.

From a clinical standpoint, the results of this study provide a sound basis for recommending the use of resin cement with PMMA sandblasting as the safest and most predictable protocol for indirect restorations. (Gad *et al.*, 2020)^[12] This recommendation helps optimize clinical decision-making, reduce the risk of adhesive complications, and improve the short- and medium-term prognosis of PMMA restorations. (Erbulak & Ergun, 2023)^[10]

Conclusions

The resin cement exhibited significantly higher bond strength compared to the preheated composite resin.

With regard to the surface treatment of PMMA, sandblasting proved to be a key factor in increasing bond strength when used in combination with resin cement.

The preheated composite resin did not demonstrate clinically reliable adhesive performance to PMMA under the study conditions.

Recommendations

Further testing using other cementing agents is recommended to compare the bond strength that PMMA can achieve, as it is a widely used material.

The use of other surface treatments is recommended to determine the behavior and interaction with PMMA.

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