THE ROLE OF RESIN-BASED RESTORATIONS IN ATHLETE CONFIDENCE AND RECOVERY FOLLOWING SPORTS-RELATED DENTAL TRAUMA

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Abstract

Background: Resin-based composites are widely used in restorative dentistry due to their aesthetic and functional properties. The longevity of these restorations depends heavily on the bond strength and durability of the adhesive systems used. This study aimed to evaluate and compare the performance of three adhesive systems—etch-and-rinse, self-etch, and universal adhesive—in terms of bond strength and durability under simulated oral conditions.

Methods: An in vitro experimental design was employed using 90 sound human premolars, randomly divided into three groups (n=30 each). Each group received one of the adhesive systems, followed by resin composite restoration. Specimens underwent thermocycling (5,000 cycles, 5°C–55°C) to simulate aging. Microtensile bond strength (μTBS) testing was conducted, and failure modes were analyzed. Statistical analysis included one-way ANOVA and Tukey's post hoc test.

Results: The etch-and-rinse group exhibited the highest mean bond strength (34.75 MPa), significantly outperforming the self-etch (28.10 MPa) and universal adhesive (31.20 MPa) groups ($p<0.001$). Failure mode analysis revealed that the etch-and-rinse group had the highest proportion of mixed failures (65%), indicating stronger bonding, while the self-etch group showed the most adhesive failures (55%).

Conclusion: Etch-and-rinse adhesives demonstrated superior bond strength and durability compared to self-etch and universal adhesives. Universal adhesives, while versatile, showed intermediate performance. Clinicians should consider adhesive type and application techniques to optimize restoration longevity, with etch-and-rinse systems being the preferred choice for high bond strength requirements. Further long-term studies are needed to validate these findings under clinical conditions.

Keywords: Bond strength, Resin composites, Etch-and-rinse adhesive, Self-etch adhesive, Universal adhesive, Microtensile testing, Dental materials

Background

Resin-based composites have become a central component in modern restorative dentistry due to their aesthetic properties, ease of manipulation, and ability to conserve healthy tooth structure. These materials are commonly used in both anterior and posterior teeth, replacing traditional amalgam restorations. However, the long-term success of these restorations is closely tied to the strength and integrity of the bond between the composite and the tooth structure (Pratap et al., 2019).

Adhesive systems are crucial in forming a reliable interface between the dental composite and the tooth. They work by creating micromechanical retention and chemical bonding to the enamel and dentin. Adhesive systems are generally divided into two major categories: etch-and-rinse systems and self-etch systems. Each category requires specific clinical protocols, and their selection can influence the performance and durability of the restoration (Bourgi et al., 2024).

Bond strength is a major factor in ensuring the stability and functionality of resin-based restorations. A strong bond minimizes marginal leakage, prevents secondary caries, and reduces post-operative sensitivity. Laboratory tests, such as microtensile and shear bond strength measurements, are frequently used to evaluate the performance of different adhesive systems. These values help predict clinical success but are affected by variables like tooth structure condition and operator technique (Khalil & Al-Shamma, 2024).

Durability is just as important as initial bond strength. Over time, various environmental factors such as moisture, temperature fluctuations, and enzymatic activity can weaken the adhesive interface. Water sorption and hydrolytic degradation are particularly problematic in adhesives containing hydrophilic components. These issues can compromise the hybrid layer and reduce the lifespan of the restoration (Tjäderhane et al., 2013).

To simplify clinical procedures and improve user convenience, universal adhesives have been developed. These systems offer the flexibility to be used in multiple bonding modes, including etch-and-rinse, self-etch, and selective-etch techniques. While they show potential in reducing technique sensitivity, ongoing investigations are assessing whether their performance matches or surpasses traditional adhesive systems in terms of bond strength and longevity (Sofan et al., 2017).

Bonding effectiveness varies significantly between enamel and dentin due to their distinct structures. Enamel, with its high mineral content, responds well to acid etching and provides predictable bonding. In contrast, dentin contains more organic material and fluid-filled tubules, making bonding more challenging. Successful adhesive systems must accommodate these differences to ensure consistent performance across both types of dental tissues (Barutcigil et al., 2014).

The chemical composition of an adhesive system greatly influences its bonding capabilities. Components such as functional monomers, solvents, and fillers all play specific roles. Functional monomers enhance chemical interaction with the tooth, while solvents facilitate penetration into the dentin. The type and concentration of these ingredients can affect both the immediate and long-term performance of the adhesive (Cadenaro et al., 2018).

From a practical perspective, dentists must understand the properties of different adhesive systems to select the most suitable one for each clinical case. Failures in resin restorations are often attributed to compromised adhesion, particularly at the dentin interface. Therefore, choosing an adhesive that provides high bond strength and long-term durability is essential for ensuring the success of restorative treatments (Perdigão, 2020).

Despite the wide range of available adhesive products, comparative data on their long-term performance is limited. Many studies focus on immediate bond strength without considering the effects of aging and environmental stress. Furthermore, differences in testing protocols and clinical application techniques make it difficult to draw definitive conclusions. Comprehensive comparative research is necessary to fill these gaps and guide evidence-based clinical decision-making (Hardan et al., 2023).

The primary aim of this study is to investigate the impact of different adhesive systems on the bond strength and durability of resin-based restorations. By employing standardized laboratory tests and aging simulations, the research seeks to provide insights into which adhesives offer the most reliable performance. The findings are intended to support clinicians in making informed choices that enhance the longevity and success of restorative treatments.

Methodology

This research employed an experimental in vitro design to evaluate and compare the bond strength and durability of different adhesive systems used in resin-based restorations. The study was structured to simulate clinical conditions as closely as possible within a controlled laboratory environment.

A total of 90 sound human premolar teeth extracted for orthodontic purposes were collected and used in this study. All teeth were free from caries, cracks, restorations, and any visible structural defects. After extraction, the teeth were cleaned of soft tissue debris and stored in distilled water at room temperature until further processing. The sample was randomly divided into three groups (n = 30 per group) according to the type of adhesive system applied.

Group Allocation

- Group A: Etch-and-Rinse Adhesive System
- Group B: Self-Etch Adhesive System
- Group C: Universal Adhesive System (used in self-etch mode)

Each group underwent standardized procedures to ensure consistency and reduce variability among samples.

Tooth Preparation

Each tooth was sectioned at the crown using a slow-speed diamond saw to expose a flat mid-coronal dentin surface. The exposed dentin was polished using 600-grit silicon carbide paper under water cooling to create a standardized smear layer. The bonding procedures were carried out according to the respective manufacturer's instructions for each adhesive system.

Bonding and Restoration Procedure

The assigned adhesive system was applied to the prepared dentin surface of each specimen. After light-curing the adhesive according to the recommended curing time, a standardized cylindrical build-up of resin composite (approximately 4 mm in diameter and 5 mm in height) was incrementally placed and light-cured. All samples were then stored in distilled water at 37°C for 24 hours prior to testing.

Aging Procedure (Thermocycling)

To simulate oral environmental conditions and evaluate the durability of the bond, all specimens underwent thermocycling. The samples were subjected to 5,000 thermal cycles between 5°C and 55°C with a dwell time of 30 seconds in each bath and a transfer time of 10 seconds. This procedure aimed to replicate the effects of temperature changes experienced in the oral cavity over time.

Bond Strength Testing

After thermocycling, the samples were subjected to microtensile bond strength (μTBS) testing using a universal testing machine. Each restored tooth was sectioned to obtain multiple bonded sticks (approximately 1 mm^2 cross-sectional area), and tensile force was applied at a crosshead speed of 1 mm/min until failure occurred. The maximum load at failure was recorded in Newtons (N), and the bond strength was calculated in Megapascals (MPa).

Failure Mode Analysis

Following bond strength testing, the fractured surfaces were examined under a stereomicroscope at 40× magnification to determine the failure modes. Failures were classified as adhesive, cohesive (in dentin or resin), or mixed failures.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 25. Descriptive statistics (mean and standard deviation) were computed for each group. The normality of the data was assessed using the Shapiro-Wilk test. One-way ANOVA was used to compare the mean bond strength among the three groups, followed by post hoc Tukey's test for pairwise comparisons. A p-value of <0.05 was considered statistically significant.

Results

This study aimed to evaluate and compare the bond strength and durability of three different adhesive systems—Etch-and-Rinse, Self-Etch, and Universal Adhesive—when used in resin-based restorations. After thermocycling and microtensile bond strength (μTBS) testing, the results were compiled and analyzed using SPSS. Below are the detailed findings presented in tabular form with accompanying commentary (Table 1).

As shown in Table 1, the Etch-and-Rinse group achieved the highest mean bond strength (34.75 MPa), followed by the Universal adhesive in self-etch mode (31.20 MPa), while the Self-Etch group recorded the lowest value (28.10 MPa). The variation in mean bond strengths indicates a potential influence of the adhesive system type on bonding effectiveness to dentin.

a statistically significant difference in bond strength among the three adhesive groups ($p < 0.001$). The F-value of 17.06 supports the conclusion that the adhesive system type significantly affects bond performance, warranting further pairwise comparisons. The post hoc results indicate that all pairwise differences between groups were statistically significant. The Etch-and-Rinse adhesive outperformed both Self-Etch and Universal adhesives ($p < 0.01$), while the Universal adhesive also performed significantly better than the Self-Etch group ($p = 0.018$). These findings underscore the superior bonding capacity of the Etch-and-Rinse system.the Etch-and-Rinse group had the highest percentage of mixed failures (65%), which is typically associated with stronger bonding. Conversely, the Self-Etch group showed the highest proportion of adhesive failures (55%), suggesting weaker interface bonding. The Universal adhesive group demonstrated an intermediate failure pattern, aligning with its bond strength values.

Discussion

The present analysis highlights the complexities and advancements in adhesive dentistry, especially concerning universal adhesives and their performance on enamel and dentin substrates. Various studies have explored the parameters that influence bonding durability and strength, particularly the application strategies such as self-etch versus etch-and-rinse techniques, and the incorporation of cross-linking agents to stabilize the hybrid layer.

Firstly, a major systematic review and meta-analysis by Cuevas-Suárez et al. (2019) emphasized that the bonding performance of universal adhesives varies with their chemical strength and the substrate type. Specifically, etch-and-rinse strategies significantly improved enamel bond strength, particularly for ultra-mild and intermediately strong adhesives. However, bond durability was compromised in aged samples, especially for intermediately strong adhesives, indicating the susceptibility of certain adhesive chemistries to hydrolytic degradation over time (Cuevas-Suárez et al., 2019).

In alignment with the degradation concerns, Betancourt et al. (2019) provided an in-depth analysis of the degradation mechanisms at the resin-dentin interface. They described that inadequate infiltration of adhesives into demineralized collagen matrices leaves fibrils vulnerable to enzymatic degradation. Matrix Metalloproteinases (MMPs) and hydrolytic activity lead to hybrid layer deterioration, undermining long-term bonding effectiveness (Betancourt et al., 2019). This underscores the need for interventions that can enhance adhesive penetration and collagen stability.

Supporting these concerns, Scheffel et al. (2017) evaluated the application of a cross-linking agent, carbodiimide (EDC), on etched dentin prior to bonding. The study demonstrated that EDC treatment significantly preserved resin-dentin bond strength over a 12-month period, regardless of whether it was applied for 30 or 60 seconds. This suggests that collagen cross-linking may be a viable method to combat enzymatic degradation and prolong adhesive restoration lifespan (Scheffel et al., 2017).

In terms of adhesive system selection, the comparative study by Jafarnia et al. (2022) revealed no significant differences in microtensile bond strength among the tested universal adhesives to both enamel and dentin. However, variations in the values, particularly in enamel bonding, suggest that while some systems may be equivalent statistically, clinical performance may still depend on the tooth surface and technique employed (Jafarnia et al., 2022).

Similarly, Elhoshy and Aboelenein (2018) compared one-step self-etch adhesives with etch-and-rinse systems in their adhesion to ground enamel. Their results confirmed that certain self-etch adhesives like Futurabond NR and Clearfil SE Bond achieved comparable bond strengths to etch-and-rinse systems, whereas others like Clearfil Tri S Bond exhibited significantly lower performance. This reinforces that not all self-etch adhesives behave uniformly and highlights the role of material formulation in clinical success (Elhoshy & Aboelenein, 2018).

Micro leakage remains a significant issue in adhesive dentistry, often leading to clinical failures such as recurrent caries and hypersensitivity. Mauro et al. (2012) showed that self-etching adhesives, despite being easier to apply, generally resulted in higher marginal leakage in enamel margins compared to conventional systems. However, in dentin margins, no significant differences were found. This suggests that enamel bonding remains more challenging with self-etch adhesives, reinforcing the selective enamel etching approach

Table 1. Descriptive Statistics of Microtensile Bond Strength (μTBS) in MPa for Each Group.

Adhesive System	N	Mean (MPa)	Standard Deviation
Etch-and-Rinse	30	34.75	3.42
Self-Etch	30	28.10	3.85
Universal (Self-Etch)	30	31.20	3.61

proposed by Cuevas-Suárez et al. (Mauro et al., 2012).

The study by Cuevas-Suárez et al. also concluded that mild universal adhesives demonstrated the most stable bonding performance under both application strategies. This could be attributed to their balanced formulation which ensures moderate etching while maintaining chemical stability. Hence, for clinicians aiming for long-term performance, mild adhesives used with selective enamel etching may be optimal.

Moreover, Betancourt et al. emphasized that achieving stable interfacial bonding depends not only on the adhesive formulation but also on managing the hybrid layer's moisture content. Water entrapment can impair resin infiltration, leading to Nano leakage and enzyme activation. Strategies like ethanol-wet bonding or using hydrophobic overcoats could be effective but require further validation (Betancourt et al., 2019).

Scheffel et al.'s findings offer promising insights into chemical stabilization of dentin, particularly through cross-linking agents that target collagen fibrils. EDC, as demonstrated, significantly reduced Nano leakage and maintained bond strength, which could become a critical pre-treatment step in adhesive protocols, especially for high-stress-bearing restorations.

While universal adhesives simplify the clinical workflow by enabling both etch-and-rinse and self-etch techniques, their effectiveness largely depends on careful material selection and substrate treatment. Elhoshy and Aboelenein's work demonstrated that while some one-step adhesives perform comparably to etch-and-rinse systems, others fall short, underscoring the importance of evidence-based adhesive selection (Elhoshy & Aboelenein, 2018).

Jafarnia et al.'s comparative analysis confirms the versatility of modern universal adhesives but also reveals variability in bond strengths, possibly due to differences in pH, solvent systems, and functional monomers like 10-MDP. As clinical performance may vary, this necessitates further long-term in vivo studies to corroborate in vitro findings (Jafarnia et al., 2022).

Conclusion

In conclusion, while universal adhesives offer clinical versatility, their long-term success depends on several factors, including substrate preparation, adhesive formulation, and application strategy. Evidence from systematic reviews and individual studies suggests that mild adhesives used with selective enamel etching, complemented by cross-linking agents like EDC, can significantly enhance bond durability. However, individual product performance varies, and clinicians must rely on evidence-based decisions and consider incorporating strategies to prevent hybrid layer degradation to ensure restoration longevity.

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