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Effect Of Cavity Disinfection Protocols On The Bond Strength And Longevity Of Direct Resin Restorations

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Abstract

Background: Residual bacterial contamination within prepared cavities can compromise the adhesive bond and reduce the longevity of resin restorations. Incorporating cavity disinfection into adhesive protocols has been proposed to improve bonding durability and clinical performance. This study aimed to evaluate the effect of different cavity disinfection protocols on the bond strength and longevity of direct resin restorations.

Methods: Eighty sound human premolars were prepared with standardized Class V cavities and randomly divided into four groups (n = 20) according to the disinfection agent used: Group I (control, no disinfectant), Group II (2% chlorhexidine gluconate), Group III (2.5% sodium hypochlorite), and Group IV (70% ethanol). Cavities were restored using a universal adhesive and nano-hybrid composite resin. Half of the specimens from each group were tested immediately for microtensile bond strength, while the other half underwent thermocycling for 10,000 cycles to simulate aging. Failure modes were examined under a stereomicroscope, and data were statistically analyzed using one-way ANOVA and Tukey's post hoc test ($p < 0.05$).

Results: Significant differences were observed among the groups ($p < 0.001$). The chlorhexidine group exhibited the highest immediate bond strength (30.5 ± 2.7 MPa) and the greatest aged bond strength after thermocycling (27.1 ± 2.3 MPa), with only an 11.1% reduction. The ethanol group showed moderate performance, while the sodium hypochlorite and control groups displayed lower values, with the control showing the highest reduction after aging (30.9%). Mixed failure modes predominated in disinfected groups, especially in the chlorhexidine group (45%), indicating stronger interfacial bonding.

Conclusion: Cavity disinfection significantly enhanced the bond strength and durability of resin restorations. The use of 2% chlorhexidine gluconate prior to adhesive application provided the most stable
and long-lasting bond, followed by ethanol and sodium hypochlorite. Incorporating chlorhexidine as a routine cavity disinfectant is recommended to improve the longevity and clinical success of direct resin restorations.

INTRODUCTION

Background

Dental caries remains one of the most prevalent chronic diseases worldwide, representing a significant public health concern. The management of carious lesions has evolved from extensive mechanical removal of affected tissue toward more conservative, minimally invasive approaches. Modern restorative dentistry emphasizes the preservation of sound tooth structure while ensuring long-term restoration success. However, even with conservative techniques, residual bacteria within the prepared cavity can jeopardize the integrity of adhesive bonds and compromise the longevity of resin restorations (Coelho et al., 2020).

Cavity disinfection has therefore gained increasing attention as a critical step prior to restorative procedures. The objective of disinfection is to eliminate or reduce the microbial load remaining after caries excavation, minimizing the risk of secondary caries formation and postoperative sensitivity. While conventional cavity cleaning relies primarily on mechanical and chemical methods, various antimicrobial agents have been introduced to improve clinical outcomes by reducing bacterial contamination at the tooth–resin interface (Sekhar et al., 2017).

Adhesive bonding systems have revolutionized restorative dentistry, allowing predictable adhesion between resin materials and tooth substrates. The durability of this bond, however, can be influenced by several factors, including the condition of the dentin surface and the presence of residual contaminants. Inadequate disinfection or improper surface treatment can weaken the hybrid layer, resulting in decreased bond strength and microleakage over time. Consequently, the integration of an effective disinfection protocol into adhesive procedures is essential for achieving optimal bonding performance and restoration longevity (James et al., 2025).

Several disinfectant agents have been proposed for use prior to adhesive application. Chlorhexidine, sodium hypochlorite, ethanol, and more recently, natural extracts and laser-based methods have been explored for their antibacterial properties and compatibility with bonding systems. The challenge lies in selecting a disinfectant that effectively eliminates microorganisms without adversely affecting the adhesive penetration or polymerization processes essential for stable bonding (Haralur et al., 2022).

The interaction between disinfectants and adhesive systems can be complex. Some disinfectants may alter the surface energy of dentin, interfere with the monomer infiltration into collagen fibrils, or affect the chemical stability of the adhesive interface. Conversely, certain agents, such as chlorhexidine, have demonstrated potential benefits in preserving the integrity of the hybrid layer by inhibiting matrix metalloproteinases responsible for collagen degradation. Understanding these interactions is crucial for optimizing restorative outcomes (Arslan et al., 2020).

Longevity of resin restorations depends not only on the immediate bond strength but also on the stability of that bond over time under oral environmental stresses. Factors such as thermal fluctuations, masticatory forces, and enzymatic degradation contribute to deterioration at the adhesive interface. Effective cavity disinfection protocols could potentially enhance both immediate and aged bond strengths by creating a cleaner, more stable substrate for adhesion (Bilgili Can et al., 2022).

The incorporation of cavity disinfection into restorative protocols also aligns with the growing emphasis on preventive and biologically oriented dentistry. Instead of focusing solely on mechanical retention, clinicians now strive to create a biologically sound environment that supports tissue preservation and long-term restoration success. This shift in philosophy underscores the importance of research into how different disinfection protocols affect adhesive performance (Kimyai et al., 2017).

While numerous studies have explored the antibacterial efficacy of various cavity disinfectants, their influence on the mechanical and chemical properties of resin–dentin bonds remain a topic of active investigation. The interplay between antimicrobial effectiveness and adhesive compatibility must be balanced to achieve both caries prevention and restoration durability (Salgueiro et al., 2023).

With advancements in adhesive technology and biomaterials, understanding how cavity disinfection protocols integrate with these systems is vital. Investigating the effects of different disinfection agents and techniques on bond strength and restoration longevity can provide valuable insights for evidence-based clinical practice (Vilela et al., 2025).

Ultimately, optimizing cavity disinfection protocols represents a key opportunity to enhance the performance of direct resin restorations. By ensuring that the dentin surface is both biologically clean and chemically receptive to bonding, clinicians can improve the predictability, durability, and overall success of restorative treatments in contemporary dental practice (Abu-Nawareg et al., 2024).

Methodology

Study Design

This study employed an in-vitro experimental design to evaluate the effect of different cavity disinfection protocols on the bond strength and longevity of direct resin restorations. The research compared multiple disinfectant agents applied to prepared dentin surfaces before adhesive procedures.

Sample Selection

A total of 80 sound human premolars extracted for orthodontic reasons were collected for this study. Teeth with caries, cracks, restorations, or structural defects were excluded. The extracted teeth were cleaned of debris and soft tissue remnants using a scaler and stored in distilled water at room temperature until use. All specimens were used within one month after extraction to ensure comparable dentin properties.

Sample Preparation

The teeth were embedded in acrylic resin blocks, leaving the coronal portion exposed. Standardized Class V cavities were prepared on the buccal surfaces using a high-speed handpiece with a cylindrical diamond bur under continuous water cooling. Each cavity measured approximately 3 mm in height, 4 mm in width, and 2 mm in depth. A new bur was used after every five preparations to maintain cutting efficiency and cavity standardization.

Grouping of Samples

The 80 teeth were randomly divided into four equal groups (n = 20 each) according to the cavity disinfection protocol used:

- **Group I (Control):** No disinfectant was applied; bonding was done directly after cavity preparation.
- **Group II (Chlorhexidine group):** Cavities were disinfected with 2% chlorhexidine gluconate solution for 60 seconds and gently air-dried.
- **Group III (Sodium Hypochlorite group):** Cavities were treated with 2.5% sodium hypochlorite for 30 seconds, followed by rinsing with distilled water and gentle air drying.
- **Group IV (Ethanol group):** Cavities were conditioned with 70% ethanol for 30 seconds and air-dried.

Adhesive and Restoration Procedure

All cavities were then treated with a universal adhesive system following the manufacturer's instructions. The adhesive was applied using a microbrush, air-thinned, and light-cured for 20 seconds using an LED curing unit with an intensity of 1000 mW/cm².

Resin composite (nano-hybrid type) was placed in two increments of 1 mm each and each increment was light-cured for 40 seconds. After curing, all restorations were finished and polished with fine-grit diamond burs and polishing discs to obtain smooth surfaces.

Storage and Aging Protocol

After restoration, the specimens were stored in distilled water at 37°C for 24 hours to allow complete polymerization. For longevity assessment, half of the specimens in each group (n = 10) were subjected to thermocycling for 10,000 cycles between 5°C and 55°C with a dwell time of 30 seconds to simulate approximately one year of clinical aging. The remaining half were tested for immediate bond strength.

Microtensile Bond Strength Testing

The teeth were sectioned longitudinally in both mesiodistal and buccolingual directions using a diamond saw under water cooling to obtain resin–dentin beams with a cross-sectional area of approximately 1 mm². Each beam was attached to a microtensile testing jig using cyanoacrylate adhesive and tested in a universal testing machine at a crosshead speed of 1 mm/min until failure occurred. The bond strength values were recorded in megapascals (MPa).

Failure Mode Analysis

The fractured specimens were examined under a stereomicroscope at 40× magnification to determine the failure mode, categorized as adhesive, cohesive in resin, cohesive in dentin, or mixed. Representative samples from each group were further examined using scanning electron microscopy (SEM) to assess the quality of the resin–dentin interface and hybrid layer morphology.

Statistical Analysis

The collected data were tabulated and analyzed using SPSS version 25.0. Descriptive statistics (mean ± standard deviation) were calculated for each group. The one-way analysis of variance (ANOVA) was used to compare mean bond strength values among groups, followed by Tukey's post hoc test for pairwise comparisons. A p-value < 0.05 was considered statistically significant.

Ethical Considerations

All extracted teeth were obtained after informed consent from donors, ensuring that the teeth were collected for reasons unrelated to this research. The study protocol adhered to the principles outlined in the Declaration of Helsinki for the ethical use of human biological materials.

Results

This study aimed to evaluate the effect of various cavity disinfection protocols on the bond strength and longevity of direct resin restorations. A total of 80 sound premolars were divided equally into four experimental groups according to the disinfection agent used: control (no disinfectant), 2% chlorhexidine gluconate, 2.5% sodium hypochlorite, and 70% ethanol. Each group was further divided into two subgroups (n = 10 each): immediate testing and aged specimens after thermocycling. The results included the mean bond strength values, distribution of failure modes, and statistical comparisons among the groups.

Table 1. Distribution of Samples According to Groups and Aging Condition

Group	Disinfectant Used	Immediate Testing (n, %)	Aged (Thermocycled) (n, %)	Total (n, %)
I	Control (No Disinfectant)	10 (12.5%)	10 (12.5%)	20 (25%)
II	2% Chlorhexidine	10 (12.5%)	10 (12.5%)	20 (25%)
III	2.5% Sodium Hypochlorite	10 (12.5%)	10 (12.5%)	20 (25%)
IV	70% Ethanol	10 (12.5%)	10 (12.5%)	20 (25%)
Total		**40 (50%)**	**40 (50%)**	**80 (100%)**

Each group contained an equal number of specimens (n = 20), with half tested immediately and half subjected to aging. This ensured balanced comparison between short-term and long-term performance of the disinfectants on bond strength.

Table 2. Mean Microtensile Bond Strength (MPa) for Each Group Before and After Thermocycling

Group	Disinfectant Used	Immediate Mean ± SD (MPa)	Aged Mean ± SD (MPa)	% Reduction After Aging	p-value (ANOVA)
I	Control	27.8 ± 2.4	19.2 ± 2.1	30.9%	<0.001*
II	2% Chlorhexidine	30.5 ± 2.7	27.1 ± 2.3	11.1%	<0.001*
III	2.5% Sodium Hypochlorite	26.9 ± 2.5	20.4 ± 2.0	24.2%	<0.001*
IV	70% Ethanol	28.7 ± 2.6	23.5 ± 2.4	18.1%	<0.001*

*Significant at $p < 0.05$

The highest immediate bond strength was observed in the chlorhexidine group (30.5 ± 2.7 MPa), followed by the ethanol group (28.7 ± 2.6 MPa), control (27.8 ± 2.4 MPa), and sodium hypochlorite group (26.9 ± 2.5 MPa).

After thermocycling, all groups showed a decrease in bond strength, but the chlorhexidine-treated samples retained the highest aged bond strength (27.1 ± 2.3 MPa) and demonstrated the lowest percentage reduction (11.1%), indicating superior durability.

The control group exhibited the greatest reduction (30.9%), reflecting weaker long-term stability without disinfection. Statistical analysis revealed significant differences between groups ($p < 0.001$), confirming that cavity disinfection protocols significantly affected both initial and aged bond strengths.

Table 3. Comparison of Failure Modes Among Groups (n = 20 per group)

Failure Mode	Control n (%)	Chlorhexidine n (%)	Sodium Hypochlorite n (%)	Ethanol n (%)	Total n (%)
Adhesive	11 (55%)	6 (30%)	9 (45%)	7 (35%)	33 (41.3%)

Cohesive in Dentin	2 (10%)	3 (15%)	2 (10%)	3 (15%)	10 (12.5%)
Cohesive in Resin	1 (5%)	2 (10%)	1 (5%)	2 (10%)	6 (7.5%)
Mixed	6 (30%)	9 (45%)	8 (40%)	8 (40%)	31 (38.7%)
Total	**20 (100%)**	**20 (100%)**	**20 (100%)**	**20 (100%)**	**80 (100%)**

The chlorhexidine group showed the highest incidence of mixed failures (45%), suggesting a stronger and more integrated bond between resin and dentin.

In contrast, the control group had the highest percentage of adhesive failures (55%), indicating weaker bonding at the interface. The ethanol and sodium hypochlorite groups showed intermediate results, with mixed failures observed in 40% of samples each. Overall, disinfected groups demonstrated fewer adhesive failures and more mixed failures compared to the control, supporting the positive influence of cavity disinfection on bond quality.

Table 4. Post Hoc Tukey Test for Pairwise Comparison of Mean Bond Strengths After Thermocycling

Groups Compared	Mean Difference (MPa)	Significance (p-value)	Interpretation
Control vs. Chlorhexidine	-7.9	<0.001*	Significant
Control vs. Sodium Hypochlorite	-1.2	0.084	Not significant
Control vs. Ethanol	-4.3	0.007*	Significant
Chlorhexidine vs. Sodium Hypochlorite	6.7	<0.001*	Significant
Chlorhexidine vs. Ethanol	3.6	0.012*	Significant
Sodium Hypochlorite vs. Ethanol	-3.1	0.041*	Significant

*Significant at $p < 0.05$

Pairwise comparisons revealed that chlorhexidine showed significantly higher bond strength than all other groups ($p < 0.05$). The ethanol group also performed significantly better than the control and sodium hypochlorite groups. Differences between control and sodium hypochlorite were not statistically significant. These findings confirm that chlorhexidine-based disinfection produced the most stable and durable adhesive bonds after aging.

Discussion

The results of this study demonstrated that cavity disinfection protocols significantly affected the bond strength and longevity of direct resin restorations. Among the disinfectants tested, 2% chlorhexidine gluconate produced the highest immediate and aged bond strength, while the control group without disinfection showed the lowest performance. These findings highlight the importance of incorporating disinfection procedures prior to adhesive application to achieve optimal bonding effectiveness and long-term stability.

The superior results obtained with chlorhexidine may be attributed to its dual role as an antimicrobial and matrix metalloproteinase (MMP) inhibitor. Chlorhexidine is known to suppress endogenous dentinal enzymes that degrade the collagen fibrils within the hybrid layer, thereby enhancing the long-term durability of the adhesive interface (Coelho et al., 2020). In the current study, the minimal reduction in bond strength after aging (11.1%) in the chlorhexidine group supports its protective effect against collagen degradation and hydrolytic breakdown.

The findings are consistent with the observations of James et al. (2025), who reported that chlorhexidine significantly improved the bonding performance of restorative materials in primary teeth compared to non-disinfected controls. Similarly, Kimyai et al. (2017) demonstrated that cavity disinfection with chlorhexidine reduced marginal gaps and improved sealing ability, thereby limiting microleakage and enhancing the overall longevity of restorations. These results suggest that chlorhexidine not only maintains the physical integrity of the bond but also contributes to a more stable restorative interface.

In contrast, sodium hypochlorite showed the lowest bond strength among the disinfected groups. Although sodium hypochlorite is a potent antimicrobial and deproteinizing agent, its oxidative properties can adversely affect the polymerization of adhesive monomers and alter the dentin surface chemistry (Salgueiro et al., 2023). The present findings align with the results of Bilgili Can et al. (2022), who found that sodium hypochlorite treatment led to reduced bond strength values when used prior to universal adhesives. This effect may be attributed to the formation of an oxygen-rich layer that inhibits resin infiltration and polymerization.

The ethanol-treated group showed intermediate bond strength values, with better results than sodium hypochlorite but lower than chlorhexidine. Ethanol is believed to promote better resin infiltration by removing residual water and enhancing surface energy of the dentin substrate (Haralur et al., 2022). Its use can improve monomer diffusion into collagen fibrils, resulting in a more homogeneous hybrid layer. In the current study, the ethanol group retained 81.9% of its bond strength after thermocycling, confirming its positive influence on adhesive durability.

The control group exhibited the greatest decline in bond strength after thermocycling (30.9%), emphasizing the detrimental impact of residual contaminants and microorganisms when no disinfection protocol is used. This outcome supports the conclusion of Arslan et al. (2020), who demonstrated that untreated dentin surfaces are more susceptible to nanoleakage and degradation, leading to premature failure of restorations. The high proportion of adhesive failures (55%) in the control group further underscores the weak interfacial bonding in the absence of disinfection.

Analysis of failure modes revealed that mixed failures predominated in disinfected groups, particularly in the chlorhexidine group (45%). This trend suggests the formation of a stronger and more cohesive adhesive interface. Similar findings were reported by Abu-Nawareg et al. (2024), who found that effective dentin cleansing protocols promote hybrid layer uniformity, resulting in mixed failure patterns rather than purely adhesive failures.

The SEM examination in comparable studies has shown that chlorhexidine-treated dentin surfaces preserve the hybrid layer morphology and resin tag formation over time, which correlates with improved mechanical performance (Vilela et al., 2025). The sustained bond integrity observed in this study after thermocycling indicates that chlorhexidine can mitigate thermal and hydrolytic stresses that normally degrade adhesive interfaces.

Another aspect influencing the results may be the compatibility between disinfectants and adhesive systems. Universal adhesives are designed to perform under a variety of substrate conditions, but their chemistry can still be affected by pre-treatment agents. As Haralur et al. (2022) observed, ethanol and chlorhexidine tend to interact more favorably with the acidic monomers in universal adhesives compared to oxidizing agents like sodium hypochlorite, which can interfere with polymerization reactions. This could explain the superior performance of chlorhexidine and ethanol in the present study.

The impact of thermocycling on bond degradation highlights the relevance of aging simulations in laboratory testing. Although all groups showed some degree of bond reduction after aging, the magnitude of decline varied substantially. The results confirm that the longevity of resin–dentin bonds is not solely determined by initial strength but also by the capacity of the interface to resist degradation mechanisms, including enzymatic and hydrolytic breakdown (Bilgili Can et al., 2022).

Furthermore, the findings reinforce the concept that cavity disinfection is not merely a microbial control step but a determinant of long-term adhesive performance. Effective disinfection ensures that the dentin substrate remains chemically stable, free of residual organic debris, and receptive to adhesive infiltration. As Coelho et al. (2020) emphasized, this integration between biological and mechanical preparation is crucial for achieving predictable clinical outcomes.

The clinical implications of these results are significant. In daily restorative practice, the routine use of cavity disinfectants such as chlorhexidine could extend the lifespan of composite restorations by improving adhesion durability and minimizing secondary caries risk. This is particularly relevant in high-caries-risk patients, where residual bacterial contamination may compromise restoration success despite adequate mechanical preparation (Sekhar et al., 2017).

The present findings also suggest that clinicians should exercise caution when using sodium hypochlorite for cavity disinfection. Although it provides excellent antimicrobial action, its potential to impair bond formation warrants careful control of application time and concentration. Alternative methods such as chlorhexidine or ethanol conditioning offer safer and more predictable outcomes for adhesive bonding procedures (Arslan et al., 2020).

Comparatively, the current study corroborates the outcomes of Vilela et al. (2025), who emphasized the importance of substrate conditioning in determining the bond strength of repaired or restored composite surfaces. Both studies conclude that appropriate surface pre-treatment plays a decisive role in achieving durable adhesion, regardless of the restorative system employed.

From a materials science perspective, these results highlight the dynamic nature of the resin–dentin interface. It is not a static connection but a hybrid structure susceptible to biochemical degradation. The protective effect observed with chlorhexidine and ethanol can be attributed to their capacity to stabilize collagen and maintain resin infiltration over time. This aligns with the findings of Abu-Nawareg et al. (2024), who reported that optimized cleaning protocols preserve resin–dentin bonds even under thermal and mechanical stress.

In summary, the evidence from this study supports the hypothesis that appropriate cavity disinfection protocols enhance both the bond strength and longevity of direct resin restorations. Chlorhexidine, in particular, demonstrated superior performance, likely due to its combined antimicrobial and anti-collagenolytic actions, while ethanol provided moderate improvements without compromising adhesion. Sodium hypochlorite, despite its antibacterial efficacy, showed reduced bonding performance due to its interference with adhesive polymerization.

Conclusion

Within the limitations of this in-vitro study, it can be concluded that cavity disinfection significantly influences the bond strength and long-term stability of direct resin restorations. The application of 2% chlorhexidine gluconate prior to adhesive placement provided the highest immediate and aged bond strengths, followed by ethanol and sodium hypochlorite. Therefore, incorporating chlorhexidine disinfection into routine restorative protocols is recommended to enhance the durability and success of adhesive restorations in clinical practice.

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