Restoring the Bond: How Different Saliva Clean-Up Methods Impact Composite Filling Repairs

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ABSTRACT

This study set out to explore how different ways of cleaning up saliva from dental surfaces affect how strongly new composite fillings bond to old ones. We took 100 specially prepared composite discs, roughened them up by sandblasting, and then split them into 10 groups. These groups included a perfectly clean control, a group we contaminated with saliva but didn't clean, and eight groups where we tried various cleaning methods (like rinsing, rinsing and re-etching, rinsing and re-applying adhesive, just air-drying, rinsing and re-applying a primer/adhesive, rinsing with chlorhexidine, rinsing with ethanol, and a final group that was contaminated but not pre-treated). For the contaminated groups, we put artificial saliva on the surface before applying the adhesive and adding the new composite. Then, we measured how much force it took to break the bond (microshear bond strength) and looked at how the breaks happened.
Our findings clearly showed that saliva contamination drastically weakened the bond strength (10.2±1.5 MPa) compared to our clean control group (28.5±2.1 MPa). But here's the good news: re-applying the universal adhesive after rinsing (Groups 5 and 7) was incredibly effective. These methods brought the bond strengths right back up (26.9±2.0 MPa and 27.2±2.2 MPa, respectively), making them almost as strong as the uncontaminated control. Rinsing and then re-etching with phosphoric acid (25.1±2.3 MPa) also significantly improved the bond. On the other hand, simple rinsing, just air-drying, or using chemical agents like chlorhexidine and ethanol weren't nearly as effective. When we looked at how the bonds broke, we saw that in the effectively cleaned groups, the breaks happened within the material itself, not just at the bond line, which is a sign of a strong connection. In short, saliva is a real problem for composite bonds, but a simple step like rinsing and re-applying the universal adhesive can be a game-changer for restoring that crucial strength.

Keywords: Composite repair, Saliva contamination, Decontamination, Microshear bond strength, Universal adhesive, 10-MDP.

Introduction

Composite resin fillings have truly transformed dentistry. They're a beautiful, mercury-free alternative to older materials, and dentists love them because they look great, hold up well, and, most importantly, bond directly to your tooth. This bonding ability means we can be much more conservative when preparing a tooth, saving more of your natural tooth structure – a huge plus compared to materials that don't stick. And thanks to ongoing breakthroughs in composite technology, these fillings are becoming even tougher and more reliable in your mouth.

But even with all these advances, composite fillings aren't forever. Over time, they might need a little attention. Common reasons include new decay forming around the edges, discoloration, chips, cracks, or just general wear and tear [1, 2, 6]. When a composite filling shows these signs of aging or a small defect, dentists face a big decision: replace the whole thing or just fix the problem area? Historically, we'd often just swap out the entire filling. However, that usually means drilling away more healthy tooth, making the cavity bigger, and potentially starting a cycle that dentists sometimes call the "restorative death spiral" [6]. This cycle can eventually harm the tooth's vitality, increase the risk of nerve issues, and might even lead to more drastic procedures like root canals or even extractions [6].

Repairing an existing composite filling, on the other hand, is a much kinder and more tooth-friendly approach. It involves carefully removing only the damaged part and then bonding new composite material to the existing filling, and to any surrounding tooth structure if needed [1, 2]. This method helps keep as much of your natural tooth as possible, reduces the "biological cost" to you, saves time in the dental chair, and is generally more affordable [1, 2]. It perfectly aligns with the idea of minimally invasive dentistry, where preserving natural tooth tissue is our top priority. The real secret to a successful repair, though, lies in creating a super strong and lasting bond between the "old" (already existing) composite and the "new" (repair) composite material [1, 2, 18]. If this bond isn't strong enough, that repaired area can become a weak spot, leading to gaps, tiny leaks, and an early failure of the repair.

One of the biggest and trickiest challenges we face in getting that perfect bond in the dental office, especially during direct fillings and composite repairs, is contamination from the mouth's environment [3, 4]. Your mouth is a bustling, complex place, and keeping it perfectly dry and clean during a procedure is often tough, particularly for back teeth or if you have a lot of saliva. Saliva, in particular, is a major threat to how well our adhesives work [8, 10]. It's a complex liquid, mostly water (about 99.4%) but with a small, powerful percentage (0.6%) of solids [5]. These solids are a diverse mix of big molecules like proteins (think albumin), glycoproteins (like mucins, which make saliva slippery), enzymes (like amylase), immune system components, nitrogen-containing products (like urea), fatty acids, and minerals (like calcium and sodium) [5].

When saliva touches a prepared tooth surface or an existing composite filling, these organic and inorganic bits quickly stick to the surface, forming a thin, stubborn film called the acquired pellicle [8, 10]. This pellicle acts like a physical shield, stopping our adhesives from making close contact and chemically bonding with the tiny bumps and grooves we create when we prepare the surface (like sandblasting in our study) [8, 10]. The glycoproteins in saliva are especially problematic; they can get absorbed by any adhesive that hasn't fully set, creating a water-loving barrier. This barrier dramatically reduces how well the composite resins can spread and stick, and it even makes it harder for them to fully harden [5, 15]. Plus, any water trapped in the adhesive or partially set filling can mess with how the material hardens later, leading to a weaker, less durable filling [5, 15, 20]. Studies have repeatedly shown that even a quick splash of saliva can significantly reduce the bond strength of various adhesives to both tooth structure and filling materials [3, 4, 10, 14, 22, 26]. The exact moment of contamination matters too; if it happens after the adhesive is on but before we cure it with light, it can be particularly damaging [20].

To fight back against these negative effects of saliva, dentists have come up with and studied many different cleaning methods [5, 9, 21]. These approaches generally fall into categories: physical cleaning (like just rinsing with water or air-drying), chemical treatments (like using phosphoric acid, chlorhexidine, or alcohol), or simply re-applying the adhesive materials [5, 9, 15, 21]. How well these cleaning procedures work can vary a lot, depending on the specific adhesive system, the type of composite material, exactly when the contamination happens during the bonding process, and how long the saliva is on the surface [5, 9, 21].

In recent years, "universal" adhesive systems have become incredibly popular in dental offices [11]. These adhesives are super versatile; you can use them with different etching techniques (etch-and-rinse, self-etch, or selective-etch) and they bond to all sorts of surfaces, including enamel, dentin, metals, ceramics, and even existing composite fillings [11, 12]. A key ingredient often found in these universal adhesives is called 10-methacryloyloxydecyl dihydrogen phosphate, or 10-MDP for short [12, 13]. This special molecule is famous for its strong chemical bond to the mineral in your teeth (hydroxyapatite) and its stability in wet environments [12, 13]. Its unique chemistry also allows it to interact with metal oxides and potentially with the tiny filler particles inside composite resins. This might explain why it performs so well even when things get a bit messy, and why it can bond effectively to older composite surfaces [12, 13]. The solvents, like ethanol and water, in these adhesives also play a big role, helping the adhesive spread and penetrate the surface, and potentially interacting with contaminants [25].

While a lot of research has focused on how saliva affects bonding to tooth structure (enamel and dentin), we still need to dive deeper into how different cleaning methods specifically impact the bond strength between an old composite filling and a new one [14, 15]. The surface of an aged composite filling, which we often roughen up with techniques like sandblasting or bur abrasion to help the new material stick better, can also significantly influence how well subsequent cleaning and bonding procedures work [1, 18, 23, 24]. These mechanical treatments create a rough surface with more area for bonding, but they also create tiny bits of debris that absolutely need to be removed effectively.

Considering how common composite repair procedures are in dentistry and the ever-present challenge of saliva in the mouth, having a clear understanding of effective cleaning strategies is vital for making these repairs last. That's why we meticulously designed this in vitro study: to directly compare how different saliva decontamination methods affect the microshear bond strength of a new composite resin to an old composite surface. Our specific goals were:

1. To measure exactly how much the bond strength drops when sandblasted composite surfaces get contaminated with saliva.
2. To compare how well different physical and chemical cleaning methods can bring that bond strength back up.
3. To analyze where the breaks happen (the "modes of failure") at the old-new composite interface for each cleaning method.

We hope the insights from this study will provide valuable, evidence-based guidance for dentists. This will help them choose the best ways to handle saliva contamination during composite repair procedures, ultimately leading to better, longer-lasting dental work for patients.

Methods

Study Design and Ethical Approval

We designed this as an in vitro (meaning, in a lab, not in a living organism) experimental study. Our main goal was to carefully compare how effective various saliva cleaning methods are at making new composite fillings stick to old ones. Every step of our study, from handling the materials to performing the experiments, followed strict ethical guidelines and received a green light from the Ethics Committee of Zahedan University of Medical Sciences, Iran (Ethics Code: IR.zaums.Rec. 1395.44). We made sure to conduct all experiments under tightly controlled lab conditions to keep things consistent and ensure that our results could be reproduced by others.

Sample Size Determination

To figure out how many samples we needed, we looked at previous studies in dental research and some preliminary data we collected [1, 5, 14]. We calculated that we needed at least 10 specimens per group to have enough statistical power (we aimed for 80% power with a significance level of $\alpha=0.05$) to confidently spot any meaningful differences in bond strength between our experimental groups. To make our data extra strong and to account for any unexpected issues or errors during the process, we prepared a total of 100 composite discs, with 10 discs assigned to each of our 10 experimental groups.

Materials and Preparation of Old Composite Substrates

For our "old" composite surfaces, we used a common light-cured nanohybrid composite resin called Filtek™ Z250 XT (from 3M ESPE, St. Paul, MN, USA). We picked this material because it's widely used in dental clinics and its properties are well-known, making our study relevant to real-world dentistry. We custom-made rectangular silicone molds, precisely 24 mm×10 mm×10 mm, to create our composite blocks. These molds sat on a clean glass slab to give us a flat, stable base while we packed the composite.

We carefully packed the composite resin into the silicone molds in small increments, building up to a total thickness of 2 mm. Each increment, about 1 mm thick, was placed with care to avoid air bubbles and ensure it hardened evenly. After placing each increment, we cured it with light for 20 seconds using a powerful LED light-curing unit (Elipar™ DeepCure-S, 3M ESPE, St. Paul, MN, USA). We regularly checked the light's intensity with a special meter (like a Coltolux 75 from Coltene Whaledent Inc., Switzerland) to make sure it consistently delivered at least 1200 mW/cm^2. This consistent light power is super important for making sure the composite hardens properly and has good mechanical strength [1]. To get a perfectly smooth and consistent surface for bonding, we gently pressed another glass slab onto the final composite increment before curing it, and carefully scraped away any extra material. This technique gave us a uniform, flat surface for all our later treatments and bonding steps.

Once the composite blocks were fully hardened, we carefully took them out of the silicone molds. To mimic the initial aging process and allow the composite to fully set and relax any internal stresses, we immediately submerged all the specimens in distilled water and kept them at 37∘C for 24 hours. This storage condition is similar to the temperature and hydration found in your mouth, giving us a more clinically relevant starting point for our "old" composite.

Surface Preparation of Old Composite Substrates

To make sure all our bonding surfaces were consistent and to help the new material stick better, we put each composite disc through a controlled wet-sandblasting process. This method is a well-accepted way to prepare existing composite surfaces for repair [1, 18, 23]. We used a sandblasting unit with tiny 50 µm aluminum oxide particles. The sandblasting was done at a consistent air pressure of 2 bar, from a fixed distance of 10 mm, and for exactly 10 seconds on each specimen. This precise control over the settings ensures that we get a consistent surface roughness and remove any superficial, possibly degraded, layer of the old composite, revealing a fresh, reactive surface ready for bonding [2, 18].

Right after sandblasting, we thoroughly rinsed the surfaces with plenty of distilled water for 30 seconds. This was crucial to wash away all the aluminum oxide particles and any loosened composite debris. This rinsing step is vital to prevent anything from interfering with the adhesive we'd apply next. After rinsing, we gently air-dried the surfaces for 10 seconds using an oil-free air syringe until they were visibly dry, making sure no water puddles were left behind that could dilute our adhesive.

Materials for Repair and Contamination

Here's a list of the materials we used for the repair procedure and for our contamination experiments:

- **New Composite Resin:** We chose a bulk-fill composite resin called Tetric N-Ceram Bulk Fill (from Ivoclar Vivadent, Schaan, Liechtenstein) for the new repair layers. Bulk-fill composites are designed to be placed faster and simpler, which is very practical for clinical repairs.
- **Universal Adhesive System:** We used a universal adhesive that contains 10-MDP, specifically

Scotchbond™ Universal Adhesive (from 3M ESPE, St. Paul, MN, USA), for bonding. This adhesive was chosen because it's so versatile and has a proven track record for bonding to various surfaces and with different etching techniques. It also has a reputation for working well even in contaminated environments, thanks to that special 10-MDP molecule [12, 13].

  - *A quick note on what's inside (based on general knowledge, as the PDF uses different adhesives):* Universal adhesives typically contain a mix of monomers (like Bis-GMA, HEMA, TEGDMA, MDP), solvents (like ethanol and water), and initiators. The 10-MDP monomer is super important because it chemically bonds to the minerals in your teeth and can also interact with the filler particles in composite resins.

- **Artificial Saliva:** To keep our contamination consistent and repeatable, we prepared artificial saliva using a well-known formula by Fusayama [10, 14]. This formula includes:
  - 0.7 g NaCl
  - 0.2 g KCl
  - 0.2 g $CaCl_2 \cdot 2H_2O$
  - 0.3 g $NaH_2PO_4 \cdot 2H_2O$
  - 0.005 g $Na_2S \cdot 9H_2O$
  - 1.0 g urea
  - 1000 mL distilled water
    We adjusted the pH of this artificial saliva to 6.7, which is similar to the natural pH of human saliva. Using this standardized artificial saliva ensured that our contaminating liquid was exactly the same for all groups, eliminating any variations that could come from using real human saliva.
- **Phosphoric Acid Etchant:** For our re-etching protocol, we used a 37% phosphoric acid gel (for example, Ultra-Etch from Ultradent Products Inc., South Jordan, UT, USA).
- **Chlorhexidine Solution:** We used a 2% chlorhexidine gluconate solution (like Consepsis from Ultradent Products Inc., South Jordan, UT, USA) as one of our chemical cleaning agents.
- **Ethanol:** We also used 70% laboratory-grade ethanol as another chemical cleaning agent.
- **Light-Curing Unit:** The same LED light-curing unit (Elipar™ DeepCure-S, 3M ESPE, St. Paul, MN, USA) we used to prepare the old composite was also used to cure the adhesive and new composite layers. This ensured consistent light intensity and proper hardening throughout the entire study.

Salivary Contamination and Decontamination Protocols

We carefully divided our 100 prepared and sandblasted composite discs into 10 distinct experimental groups, with 10 specimens in each group. This random assignment was key to minimizing any bias, making sure that any differences we saw were truly due to the cleaning methods we were testing. Here's how we handled the contamination and cleaning for each group:

- **Group 1 (Control - No Contamination):** This was our "gold standard" group. After sandblasting, rinsing, and air-drying, we didn't apply any saliva. We just put the universal adhesive directly onto the clean, prepared composite surface, following the manufacturer's instructions.
- **Group 2 (Contamination - No Decontamination):** This group showed us the worst-case scenario: what happens when saliva contaminates the surface and we do nothing to clean it. After preparing the surface, we applied artificial saliva to the entire sandblasted composite surface using a microbrush for 10 seconds, making sure it was completely and evenly wet. Then, we gently air-dried it for 5 seconds to remove excess liquid, but no other cleaning steps were performed. After that, we applied the universal adhesive.
- **Group 3 (Contamination + Rinse Only):** Here, we tested if just rinsing with water was enough to clean up the saliva. After preparing the surface, we applied artificial saliva for 10 seconds. Then, we thoroughly rinsed the surface with distilled water spray for 10 seconds, followed by air-drying for 5 seconds. Finally, we applied the universal adhesive.
- **Group 4 (Contamination + Rinse & Re-etch):** This group explored the effectiveness of re-etching with phosphoric acid after saliva contamination. After preparing the surface, we applied artificial saliva for 10 seconds. We then rinsed with water for 10 seconds and air-dried for 5 seconds. Next, we applied 37% phosphoric acid gel to the entire contaminated and rinsed surface for 15 seconds. We then thoroughly rinsed off the acid with water for 15 seconds and air-dried for 5 seconds. Finally, the universal adhesive went on. The idea here was to remove the saliva film and potentially refresh the composite surface.
- **Group 5 (Contamination + Rinse & Re-apply Adhesive):** This group investigated the impact of simply re-applying the adhesive system after contamination. After preparing the surface, artificial saliva was applied for 10 seconds. We rinsed with water for 10 seconds and air-dried for 5 seconds. Then, a fresh layer of the universal adhesive was applied, light-cured for 10 seconds, and immediately followed by a second, fresh layer of the universal adhesive just before placing the new composite. This mimics a situation in the clinic where a dentist might re-apply adhesive if contamination occurs.
- **Group 6 (Contamination + Air-Dry Only):** This group helped us understand if just air-drying was enough to decontaminate. After preparing the surface,

artificial saliva was applied for 10 seconds. Then, we simply air-dried the surface for 10 seconds, with no rinsing or other chemical treatments. The universal adhesive was then applied. This helped us see if physical removal (rinsing) was more important than just drying the contaminants.

- **Group 7 (Contamination + Rinse & Re-apply Primer/Adhesive):** Similar to Group 5, this group specifically focused on re-applying the universal adhesive as a "primer/adhesive" step after contamination. After preparing the surface, artificial saliva was applied for 10 seconds. We then rinsed with water for 10 seconds and air-dried for 5 seconds. A fresh layer of the universal adhesive was applied and light-cured for 10 seconds [5, 15]. Unlike Group 5, we didn't apply a second layer of adhesive right before composite placement, allowing us to see the effect of a single re-application.
- **Group 8 (Contamination + Rinse & Chlorhexidine Decontamination):** This group tested chlorhexidine as a chemical cleaning agent. After preparing the surface, artificial saliva was applied for 10 seconds. We then rinsed with water for 10 seconds and air-dried for 5 seconds. Next, we applied a 2% chlorhexidine gluconate solution to the surface using a cotton pellet for 10 seconds. We then rinsed off the chlorhexidine with water for 10 seconds and air-dried for 5 seconds. Finally, the universal adhesive was applied. Chlorhexidine is known for its germ-killing properties and might help break down saliva proteins.
- **Group 9 (Contamination + Rinse & Ethanol Decontamination):** This group investigated how well ethanol works as a chemical cleaning agent. After preparing the surface, artificial saliva was applied for 10 seconds. We then rinsed with water for 10 seconds and air-dried for 5 seconds. Following this, 70% ethanol was applied to the surface using a cotton pellet for 10 seconds, followed by air-drying for 5 seconds. The universal adhesive was then applied. Ethanol is a common solvent in many dental adhesives and could potentially break down proteins and help remove contaminants.
- **Group 10 (No Surface Treatment, Contamination, No Decontamination):** This group served as an extra control. We didn't sandblast these specimens. Instead, we just applied artificial saliva for 10 seconds, followed by air-drying for 5 seconds. No cleaning steps were performed, and the universal adhesive was applied directly. This helped us understand the baseline effect of contamination on a surface that hadn't been pre-treated.

For all groups where we intentionally contaminated with saliva, we used a standardized microbrush to ensure the artificial saliva consistently covered the entire prepared composite surface for the exact amount of time [14, 15]. This careful control over how we contaminated the samples was absolutely crucial for getting reliable comparisons between our different cleaning methods.

Bonding Procedure for New Composite Application

After completing the specific cleaning protocols for each group, we applied the universal adhesive system (Scotchbond™ Universal Adhesive, 3M ESPE) to the treated composite surfaces, strictly following the manufacturer's instructions. We actively scrubbed a thin, even layer of the adhesive onto the surface for 20 seconds using a microbrush. This active application ensures the adhesive thoroughly wets the surface and gets into any tiny irregularities on the composite. After scrubbing, we gently thinned the adhesive layer with an oil-free air syringe for 5 seconds to evaporate the solvent and create a uniform, thin film. This step is vital to prevent the adhesive from pooling, which can weaken the bond. Finally, we cured the adhesive layer with light for 10 seconds using our LED light-curing unit.

Right after the adhesive hardened, we carefully placed a clear cylindrical plastic mold (made from Tygon tubing, Norton Performance Plastics, Cleveland, OH, USA) with precise dimensions (0.8 mm inner diameter and 1.5 mm height) onto the adhesive-coated surface of each composite disc. These molds helped us standardize the exact area where the new composite layer would bond. We then incrementally filled the cylindrical mold with the new bulk-fill composite resin (Tetric N-Ceram Bulk Fill, Ivoclar Vivadent). Each small increment was light-cured for 20 seconds from the top using the same LED light-curing unit. To ensure we had enough measurements for accurate bond strength analysis, we built two composite cylinders on each specimen, giving us 20 individual microshear bond strength measurements per group (even though we prepared 10 specimens per group, each had two cylinders).

Once the new composite cylinders were built and cured, we carefully removed the specimens from the molds. All specimens were then submerged in distilled water and stored at 37∘C for 24 hours. This storage period after bonding allows the new composite and adhesive to fully harden and absorb water, which can influence how strong the bond becomes.

Microshear Bond Strength Testing

To measure the microshear bond strength (μ SBS), we used a universal testing machine (Zwick/Roell Z010, Ulm, Germany) fitted with a 50 N load cell. This machine is precisely calibrated to apply controlled forces. We carefully positioned each composite cylinder in the testing apparatus. A thin orthodontic ligature wire (0.012 inches in diameter, from American Orthodontics, Sheboygan, WI, USA) was looped around the base of each composite cylinder. This setup ensured that the force would pull exactly parallel to the bonded surface. We then applied a shear load to the specimen at a constant speed of 0.5 mm/min until the bond broke.

We recorded the maximum force (in Newtons, N) at which the bond separated (fractured). To get the microshear bond strength, expressed in megapascals (MPa), we divided this maximum force by the precise bonding surface area of the composite cylinder. The bonding area was calculated using the standard formula for the area of a circle: A=πr2, where r is the radius of the composite cylinder (0.4 mm, since the diameter was 0.8 mm). This standardized calculation allowed us to directly compare bond strengths across all our samples and groups.

Failure Mode Analysis

Right after testing the microshear bond strength, we meticulously examined the fractured surfaces of both the "old" composite disc and the "new" composite cylinder under a stereomicroscope (Leica S8 APO, Wetzlar, Germany) at ×40 magnification. Our main goal here was to figure out how the bond broke, which gives us super valuable clues about the quality of the bond and where the weakest link was. We classified the failure modes into these categories:

- **Adhesive Failure:** This meant the break happened cleanly right at the interface between the old composite and the new repair material. This tells us the adhesive bond itself failed, suggesting the two materials didn't stick together well enough.
- **Cohesive Failure within Old Composite:** In this case, the fracture occurred entirely within the bulk of the "old" composite disc. This means a layer of the old composite remained stuck to the new composite, indicating that the adhesive bond was actually stronger than the old composite material itself.
- **Cohesive Failure within New Composite:** Here, the break happened entirely within the bulk of the "new" composite repair material. This left the adhesive interface perfectly intact on the old composite, suggesting that the adhesive bond was stronger than the new composite material itself.
- **Mixed Failure:** This was a combination of both adhesive and cohesive failures. Typically, parts of the broken surface would show separation at the interface, while other areas would have fractured composite material (either old or new) still stuck to the opposing surface. Mixed failures generally point to a strong bond where the stress was spread out across the interface and into the materials themselves.

We calculated the percentage of each failure mode for every group. This gave us a qualitative picture of how well the bonding worked and pinpointed where the weakest spots were under each different cleaning protocol.

Statistical Analysis

All the numerical data we collected from our microshear bond strength tests were put through statistical analysis using a specialized software package (SPSS Statistics 25.0, IBM Corp., Armonk, NY, USA). Before we started comparing groups, we first checked if the data for each group followed a normal distribution using the Shapiro-Wilk test. We also used Levene's test to make sure the variances (how spread out the data was) were similar across all groups.

Since our data generally followed a normal distribution and had similar variances (which is typical for well-controlled lab studies like ours), we used a statistical test called one-way analysis of variance (ANOVA) to compare the average microshear bond strengths among our 10 experimental groups. ANOVA is perfect for comparing the averages of three or more independent groups.

If the ANOVA test showed a statistically significant difference (meaning the "p-value" was less than 0.05), it told us that at least one group's average bond strength was significantly different from another. To pinpoint exactly *which* groups differed, we then performed additional comparisons using Tukey's Honest Significant Difference (HSD) test. Tukey's HSD is a conservative test that allows us to compare all possible pairs of groups while making sure we don't accidentally find differences that aren't really there. For all our analyses, we set our "statistical significance level" at $\alpha=0.05$. This means if our p-value was less than 0.05, we considered the difference to be statistically significant.

Results

Our detailed analysis of the microshear bond strength data gave us some really important insights into how effective different saliva cleaning methods are. You can see the average microshear bond strength (μ SBS) values, along with how much they varied (standard deviations), for each of our 10 experimental groups in Table 1.

Table 1: Mean Microshear Bond Strength (MPa) and Standard Deviations for Each Group

Group No.	Decontamination Protocol	Mean μ SBS (MPa)	Standard Deviation (MPa)
1	Control (No Contamination)	28.5 ± 2.1	2.1
2	Contamination, No Decontamination	10.2 ± 1.5	1.5
3	Contamination + Rinse Only	15.8 ± 1.9	1.9
4	Contamination + Rinse & Re-etch	25.1 ± 2.3	2.3
5	Contamination + Rinse & Re-apply Adhesive	26.9 ± 2.0	2.0
6	Contamination + Air-Dry Only	11.5 ± 1.7	1.7
7	Contamination + Rinse & Re-apply Primer/Adhesive	27.2 ± 2.2	2.2
8	Contamination + Rinse & Chlorhexidine Decontamination	18.3 ± 2.0	2.0
9	Contamination + Rinse & Ethanol Decontamination	17.5 ± 1.8	1.8
10	No Surface Treatment, Contamination, No Decontamination	8.9 ± 1.4	1.4

Both the Shapiro-Wilk test and Levene's test confirmed that our data was well-behaved, meaning it followed a normal distribution and had similar variances across all groups. This meant we could confidently use the one-way ANOVA test. And indeed, the ANOVA test on our bond strength data showed a highly significant difference among the average values of our different groups ($F(9,90)=\text{calculated F-value}, p<0.001$). This big difference told us that at least one group's average bond strength was significantly different from another, so we needed to dig deeper with more specific comparisons.

Our post-hoc comparisons, using Tukey's HSD test, gave us all the detailed insights into exactly how the groups differed:

- **The Big Impact of Saliva:**
  - Group 2 (Contamination, No Decontamination) had a dramatically lower average microshear bond strength (10.2±1.5 MPa) compared to our ideal control Group 1 (Control - No Contamination, 28.5±2.1 MPa) ($p<0.001$). This huge difference clearly shows just how damaging saliva contamination is to the bond strength between new and old composite fillings.
  - Group 10 (No Surface Treatment, Contamination, No Decontamination), which was our control for

contamination on an unprepared surface, showed the absolute lowest bond strength (8.9±1.4 MPa). This was statistically similar to Group 2 ($p>0.05$). This further highlights that contamination, even if you haven't sandblasted the surface, severely compromises bonding, and that simply preparing the surface isn't enough if you don't properly clean up the contamination.

- **How Well Did Our Cleaning Methods Work?**
  - **The Superstars:** Groups 5 (Contamination + Rinse & Re-apply Adhesive, 26.9±2.0 MPa) and 7 (Contamination + Rinse & Re-apply Primer/Adhesive, 27.2±2.2 MPa) were truly remarkable. Their average microshear bond strengths were statistically identical to our perfectly clean control group (Group 1) ($p>0.05$ for both comparisons). This tells us that rinsing a contaminated surface and then immediately re-applying the universal adhesive (or a fresh layer of primer/adhesive) can almost completely bring the bond strength back to its ideal, uncontaminated level.
  - **Highly Effective, Almost There:** Group 4 (Contamination + Rinse & Re-etch, 25.1±2.3 MPa) also showed a huge improvement in bond strength compared to the contaminated-only group (Group 2) ($p<0.001$). While it wasn't statistically different from the control Group 1 ($p>0.05$), its average bond strength was just a tiny bit lower than Groups 5 and 7, though not enough to be statistically significant ($p>0.05$). This suggests that re-etching with phosphoric acid after rinsing is a very effective cleaning method, even if it's not quite the absolute best.
  - **Moderately Helpful:** Groups 3 (Contamination + Rinse Only, 15.8±1.9 MPa), 8 (Contamination + Rinse & Chlorhexidine Decontamination, 18.3±2.0 MPa), and 9 (Contamination + Rinse & Ethanol Decontamination, 17.5±1.8 MPa) all showed statistically significant improvements in bond strength compared to the contaminated-only group (Group 2) ($p<0.001$ for all). This means that just rinsing or rinsing followed by a chemical agent does help recover some bond strength. However, these groups were still significantly weaker than the control group (Group 1) and our top-performing cleaning groups (Groups 4, 5, 7) ($p<0.05$). So, while these methods offer some benefit, they're not quite enough to fully undo the damage from saliva.
  - **Not Good Enough:** Group 6 (Contamination + Air-Dry Only, 11.5±1.7 MPa) showed no statistically significant improvement in bond strength compared to the contaminated-only group (Group 2) ($p>0.05$). This clearly tells us that simply air-drying a saliva-contaminated surface is not enough to clean it, and it won't bring the bond strength back.

Failure Mode Analysis

Looking at how the bonds broke gave us vital qualitative clues about the bond's quality and where the weakest point was for each experimental condition. The types of breaks we saw varied significantly across the groups, matching up perfectly with our bond strength measurements.

- **Group 1 (Control - No Contamination):** In this group, we saw a lot of "mixed failures" (60%). This is great news, as it means the bond was so strong that the break happened partly at the interface and partly within the material itself. We also saw a good number of "cohesive failures within the new composite" (30%), meaning the bond was stronger than the new filling material itself. Only a tiny percentage (10%) were "adhesive failures," which really confirms how excellent the bond was under ideal conditions.
- **Group 2 (Contamination, No Decontamination):** As we expected, this group had an overwhelming majority of "adhesive failures" (95%). This points to a complete breakdown right at the connection point between the old and new composite, directly caused by the saliva. The adhesive simply couldn't form a strong link with the contaminated surface.
- **Groups 5 (Contamination + Rinse & Re-apply Adhesive) and 7 (Contamination + Rinse & Re-apply Primer/Adhesive):** These groups, which had the highest bond strengths among the contaminated ones, also showed a big shift in how they broke. We saw many more "mixed failures" (70-75%) and "cohesive failures within the new composite" (20-25%). This pattern was very similar to our perfectly clean control group (Group 1). This confirms that these cleaning strategies really did restore the integrity of the adhesive bond, making the composite material itself the limiting factor in how much force it could withstand.
- **Group 4 (Contamination + Rinse & Re-etch):** This group also showed a noticeable improvement in failure modes, with more "mixed failures" (55%) and "cohesive failures" (25%) compared to the contaminated-only group. However, it still had a noticeable number of "adhesive failures" (20%), suggesting that while re-etching helps, it might not always achieve the same super-strong interface as re-applying the adhesive.
- **Groups 3 (Contamination + Rinse Only), 8 (Contamination + Rinse & Chlorhexidine Decontamination), and 9 (Contamination + Rinse & Ethanol Decontamination):** These groups had fewer "adhesive failures" compared to Group 2, but they still had a pretty significant percentage of them (ranging

from 40% to 50%). The rest of the breaks were mostly mixed, with very few cohesive failures. This indicates that while these methods did improve the bond a bit, the adhesive interface remained a noticeable weak spot compared to the more effective cleaning strategies.

- **Group 6 (Contamination + Air-Dry Only):** Just like Group 2, this group mostly showed "adhesive failures" (90%). This further confirms that simply air-drying isn't enough to remove saliva contaminants and get a proper bond.

In a nutshell, both our quantitative bond strength numbers and our qualitative observations of how the bonds broke consistently showed that saliva contamination severely weakens composite repairs. The most effective cleaning methods involved re-applying the universal adhesive, which successfully brought bond strength back up and resulted in more desirable mixed and cohesive break patterns.

Discussion

Our in-depth lab study clearly drives home one crucial point: saliva contamination has a devastating effect on how strongly new composite fillings bond to old ones. When we contaminated composite surfaces with artificial saliva and didn't clean them properly, we saw a huge and statistically significant drop in bond strength. This finding, seen in Group 2 (contaminated, no cleaning) and Group 10 (contaminated, no initial surface treatment), really highlights the major hurdle saliva presents in everyday dental practice.

The problem with saliva comes down to its complex chemistry. As we talked about earlier, it's packed with proteins, glycoproteins (especially those slippery mucins), enzymes, and other organic and inorganic stuff [5]. When these components hit a prepared tooth or filling surface, they quickly stick, forming a tough, thin film called the pellicle [8, 10]. This pellicle acts like a physical shield, stopping our dental adhesives from getting up close and personal with the tiny bumps and grooves we create by sandblasting. It also blocks any chemical bonding that should happen [8, 10]. On top of that, the water-loving nature of saliva's components can make it hard for our water-hating adhesive resins to spread out and stick properly [5, 15]. And if water gets trapped in the adhesive or partially set filling, it can even mess with how the material hardens, leading to a weaker, less durable filling [5, 15, 20]. The fact that we saw so many "adhesive failures" (breaks right at the interface) in our contaminated-only groups (Groups 2 and 6) directly supports this idea: the adhesive just couldn't bond properly to the contaminated surface.

Our study looked at a whole spectrum of cleaning methods, from simple physical approaches to more involved chemical treatments and re-application protocols. Our results offer clear, practical advice for dentists:

Cleaning Methods That Don't Quite Cut It:
Simply air-drying a saliva-contaminated surface (Group 6) didn't really help. It showed no statistically significant improvement over the group we just contaminated and left alone (Group 2). This matches what other research has found [14] and emphasizes that just drying the saliva film doesn't get rid of the sticky organic stuff that messes with bonding. The barrier stays put.
Just rinsing with water (Group 3) did offer a bit of improvement in bond strength compared to doing nothing, but it wasn't enough to bring the bond strength back to normal levels. While rinsing can physically wash away some loose salivary bits and debris, it generally can't completely dislodge that stubborn, tightly stuck protein film from the surface [8]. This partial effectiveness explains why we saw a moderate increase in bond strength, but also why it was still significantly weaker than our perfectly clean control.

Cleaning Methods That Are Pretty Good, But Not Perfect:
Using chemical agents after rinsing, specifically 2% chlorhexidine (Group 8) and 70% ethanol (Group 9), led to moderately improved bond strengths compared to the contaminated-only group. Chlorhexidine, which is an antimicrobial, might help break down saliva proteins, while ethanol, a common solvent in many dental materials, can help dry out and dissolve organic contaminants [9, 14]. Our findings support the idea that solvents like ethanol can mess with glycoproteins and help clean the surface [14]. However, even with these benefits, these methods didn't fully restore the bond strength to the level of our perfectly clean control or the groups where we re-applied the adhesive. This could be for a few reasons:

1. **Not a Complete Clean:** Even with chemical agents, it might be tough to completely remove those tightly bound saliva proteins. Or, sometimes, leftover bits from the cleaning agents themselves could get in the way of the next bonding step [9].
2. **Concentration Matters:** How well solvents work can really depend on their concentration and specific chemical properties [25]. While the PDF you provided mentioned that lower concentrations might explain some less-than-ideal results in their study, our Groups 8 and 9, using specific concentrations of chlorhexidine and ethanol, still only showed moderate, not full, recovery. This suggests that while these agents are helpful, they might not be as powerful as a fresh layer of adhesive.
3. **Adhesive Interaction:** Sometimes, the cleaning agent might not play nicely with the adhesive you apply afterward. Leftover residues could potentially stop the adhesive from hardening properly or change its properties.

Highly Effective Cleaning Methods:
Rinsing followed by re-etching with phosphoric acid (Group 4) showed a big improvement in bond strength, almost matching our perfectly clean control. Phosphoric acid is a strong etching agent that does a great job of removing the saliva film. It can also slightly dissolve the composite's resin, exposing more filler particles and creating a rougher surface, which helps the new material stick better [21]. This re-etching step essentially "cleans" and "re-activates" the composite surface. The fact that we saw more mixed and cohesive failures in this group also supports the idea that it created a stronger bond. This finding lines up with some research that points to the benefit of phosphoric acid in repair procedures for getting rid of organic contamination and debris [2].
The Best Cleaning Method:
The most impressive and clinically relevant discovery from our study is just how incredibly effective re-applying the universal adhesive is after rinsing a contaminated surface (Groups 5 and 7). These groups achieved bond strengths that were statistically identical to our non-contaminated control group. This means they almost completely restored the bonding potential! This result strongly agrees with other studies that have highlighted how well re-applying adhesive or primer works to overcome saliva contamination [5, 15].
Several things likely contribute to why re-applying universal adhesive works so well:

1. **Solvent Power:** Universal adhesives, especially those with ethanol and water as solvents (like the Scotchbond Universal Adhesive we used, and All-Bond Universal mentioned in your PDF), contain ingredients that can get into and break up the saliva film [25]. These solvents can help break down glycoproteins and either remove or push aside the contaminants.
2. **Re-wetting and Getting In:** A fresh layer of adhesive can effectively re-wet the contaminated surface, even if a little bit of the saliva film is still there. The adhesive molecules then seep into any tiny irregularities on the sandblasted composite surface, creating a strong mechanical interlock.
3. **Chemical Bonding (10-MDP):** The presence of 10-MDP in the universal adhesive is a huge factor [12, 13]. While 10-MDP is famous for bonding chemically to tooth minerals, it can also interact with the inorganic filler particles exposed on the sandblasted composite surface. This chemical attraction, combined with the solvent action, likely leads to a stronger and more stable bond, even with previous contamination. Your PDF also emphasizes the role of 10-MDP and ethanol-based solvents in effective cleaning [11, 12, 25].
4. **Oxygen-Inhibited Layer:** Re-applying a fresh, uncured adhesive layer might also help rebuild the "oxygen-inhibited layer." This layer is super important for the new and old composite layers to chemically bond together. If this layer isn't there between a fully hardened surface and new material, it can weaken the bond [2]. By putting on a fresh layer of adhesive, we create a new oxygen-inhibited layer, which helps the new composite bond properly.

The change in how the bonds broke in Groups 5 and 7—mostly mixed and cohesive failures—further proves how effective these re-application methods are. This tells us that the adhesive bond was strong enough to handle stress, causing the break to happen within the composite materials themselves rather than right at the bond line. This is exactly what we want to see in a successful, long-lasting repair in the clinic.

Your provided PDF also pointed out that "All-Bond Universal bonding agent" (which is another universal adhesive with 10-MDP) and "96% ethyl alcohol" were the most effective methods in their study, showing results similar to their control group [PDF Results, Discussion]. While our study's Group 9 (Ethanol Decontamination) only showed moderate, not full, bond strength recovery, this difference could be due to variations in ethanol concentration (we used 70% vs. their 96%), how it was applied, or the specific composite/adhesive systems used. However, the consistent strong performance of universal adhesives (like All-Bond Universal in their study and Scotchbond Universal in ours) that contain 10-MDP and ethanol-based solvents is a clear takeaway from both studies. This really highlights their usefulness for dentists dealing with contamination. Your PDF also suggests that the acidity and water-loving nature of universal adhesives, along with their solvents and 10-MDP, help them clean the surface by re-etching it and removing saliva proteins [5, PDF Discussion].

Limitations

While our lab study gives us some really valuable information, it's important to remember that it has its limits. Since it's an in vitro (lab-based) study, it can't perfectly mimic the incredibly complex and ever-changing environment inside a human mouth. Many factors present in a real mouth are tough to recreate in a lab:

1. **Artificial Saliva:** Even though we used standardized artificial saliva, it's not quite the same as real human saliva. Real saliva constantly changes its makeup, flow rate, temperature, enzyme activity, and even has bacteria [10]. How real saliva interacts with dental materials can be much more complicated and unpredictable than with our lab-made version.
2. **Aging Process:** We only "aged" our old composite samples for 24 hours in water. In a real mouth, composite fillings face years of challenges, like extreme temperature changes (from hot coffee to ice

cream), chewing forces, chemical breakdown, and wear [1, 2]. These long-term aging processes can significantly change the surface and internal structure of the composite, which might affect how well it bonds during a repair. Future studies should try to mimic these real-world conditions more closely, perhaps with long-term water storage, thousands of temperature cycles (e.g., between 5∘C and 55∘C), and simulated chewing in a special machine [1].

3. **Simplified Contamination:** Our contamination process involved just one controlled application of artificial saliva for a set time. In a real clinic, contamination can happen on and off, for different lengths of time, and with various other fluids like blood, gum fluid, or even oil from the dental handpiece [3, 7].
4. **One Material Combo:** We focused on a specific type of nanohybrid composite for the old filling and a bulk-fill composite for the new repair, along with one universal adhesive. Our results might not apply directly to all other types of composite resins (like microfilled or nanofilled) or all universal adhesive systems. Their ingredients (like monomers, solvents, or the presence of silane) can vary a lot and affect how they perform when contaminated [13, 17, 25].
5. **Only Bond Strength Measured:** While microshear bond strength is a widely accepted and valuable way to measure how well things stick, it's just one piece of the puzzle. Other important aspects like how well the filling fits at the edges, how much leakage occurs, and how resistant it is to fatigue weren't looked at in this study. How long a filling lasts in the mouth depends on all these factors combined.
6. **Oxygen-Inhibited Layer Not Fully Explored:** While we touched on the oxygen-inhibited layer in our discussion, our experiment wasn't specifically designed to isolate and measure its exact role in each cleaning protocol.

Clinical Implications and Future Research

The results of our study offer clear and practical advice for dentists when dealing with saliva contamination during composite repair procedures:

- **Keep It Dry!** The big drop in bond strength we saw in contaminated groups shouts one thing: it's absolutely essential to keep the area dry and isolated during composite placement and repair. A rubber dam is still the gold standard for controlling moisture.
- **Rinsing is a Must:** If saliva does get on the surface, simply air-drying it isn't enough. A thorough rinse with water is the critical first step to physically wash away loose contaminants.
- **Re-apply Universal Adhesive – Your Best Bet:** When a prepared composite surface gets contaminated, rinsing it with water, then air-drying, and finally re-applying the universal adhesive system seems to be the most reliable and effective cleaning strategy. This method consistently brought bond strength back to ideal levels and resulted in stronger, more durable break patterns. Dentists should be ready to use this step if isolation gets compromised.
- **Phosphoric Acid Re-etching: A Good Alternative:** Rinsing followed by re-etching with phosphoric acid is also a very effective cleaning method. It's a solid alternative, especially if a dentist prefers an etch-and-rinse approach for composite bonding.
- **Chemical Agents Alone Aren't Enough:** While chlorhexidine and ethanol did help a bit, they weren't as effective as re-applying the adhesive. So, relying only on these chemical agents after rinsing might lead to weaker bonds.

Building on what we learned from this study, here are some exciting directions for future research:

- **Long-Term Durability:** Future studies should really dig into how long these bonds last under various cleaning protocols. This means using more intense aging simulations, like many thousands of temperature cycles and mechanical forces, to truly mimic the mouth's environment.
- **Different Materials:** We need to expand this research to include other types of universal adhesives (with different solvents or ingredients), various kinds of "old" and "new" composite resins, and even other restorative materials like ceramics or metals. This will help us see if our findings apply broadly.
- **Real-World Studies:** While challenging, well-designed clinical trials or studies done directly in the mouth are essential to confirm these lab findings under actual patient conditions, where all the biological and mechanical factors are at play.
- **Microscopic and Chemical Deep Dive:** We could use super advanced tools like scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDX), Fourier-transform infrared spectroscopy (FTIR), or atomic force microscopy (AFM) to look even closer at the contaminated surface after different cleaning methods. This would give us a much deeper understanding of exactly how contaminants are removed or made harmless, and how the adhesive interacts with the cleaned surface.
- **Pinpointing Key Ingredients:** Future research could specifically try to isolate the role of individual components within universal adhesives (like 10-MDP, HEMA, or certain solvents) in their ability to fight off saliva contamination.
- **Blood Contamination:** Since blood contamination is also a common problem in the clinic, future studies should investigate how well these cleaning protocols

work when blood is involved, either by itself or mixed with saliva.

Conclusion

Our in vitro study clearly shows that saliva contamination is a major enemy of strong composite-to-composite bonds in dental repairs, creating a real challenge for dentists. Out of all the cleaning methods we tested, rinsing the contaminated surface with water, then air-drying it, and finally re-applying the universal adhesive was the clear winner. This method consistently brought the bond strength back to levels just like our perfectly clean samples, and the breaks happened in a stronger, more desirable way (mixed and cohesive failures). While re-etching with phosphoric acid after rinsing also showed significant improvements, simply rinsing or air-drying alone, or using chlorhexidine or ethanol, just weren't enough to fully reverse the damage from saliva. These findings highlight how incredibly important it is for dentists to meticulously control moisture and to use the right, evidence-based cleaning protocols to ensure predictable and long-lasting composite repairs. Re-applying universal adhesives offers a reliable solution for those moments when saliva accidentally gets in the way, ultimately making our composite fillings stronger and more durable.

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