Tufts UNIVERSITY | School of Dental Medicine

Effect of bonding agents used as lubricants on color stability of composite restorations.

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Advanced Education in Esthetic and Operative Dentistry (AEEOD)
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Abstract:

Objective:

This in vitro study aimed to evaluate the effect of different bonding agents used as lubricants during composite placement on the color stability of resin-based restorations when exposed to common staining agents over time.

Materials and Methods:

A total of 120 Tetric EvoCeram composite specimens were prepared and divided into four groups: control (no lubricant), Scotchbond Universal Plus, Excite F, and Wetting Resin. Each Specimen was subjected to staining solutions (water, coffee, or red wine) and stored at 37 °C. Color measurements were recorded using a digital spectrophotometer (VITA Easyshade® V) at baseline, 2 weeks, and 4 weeks, following ISO/TR 28642:2016 guidelines. Color change (ΔE^*) was calculated using the CIELAB formula. Statistical analysis was performed using one-way ANOVA, post hoc tests, and paired t-tests ($p < 0.05$).

Results:

At 2 weeks, significant differences in ΔE values were observed between groups under coffee staining ($p = 0.010$), with Wetting Resin showing the lowest discoloration, followed by Scotchbond Universal Plus and Excite F, while the Control group exhibited the highest color change. Wine caused the highest ΔE **values**, followed by coffee and water. By 4 weeks, although ΔE values increased in all groups, differences between bonding agents were no longer statistically significant. Time-dependent discoloration was observed across all groups, with the most significant ΔE increases occurring in red wine, followed by coffee and water.

Conclusion:

Bonding agents used as lubricants can significantly influence the early color stability of

composite restorations, particularly under aggressive staining. Wetting Resin provided the best resistance to discoloration, suggesting its potential advantage in esthetically sensitive restorations. However, the protective effect diminishes over time, highlighting the importance of long-term evaluation.

Significance:

This study suggests that using bonding agents as lubricants during composite placement does not adversely affect color stability and may offer a protective effect under staining conditions. While these findings are limited to in vitro settings, they support incorporating this technique with composite restorations.

Dedication

First and foremost, I dedicate this work with gratitude to Allah, the Most Merciful, for giving me strength, patience, and guidance throughout this journey.

To my parents — Mama and Baba — for their endless prayers, unwavering faith in me and my dreams, and for always encouraging and supporting me no matter what. Your belief in me gave me strength when I doubted myself.

To my brothers Aseel, Faisal, Bilal, and Rayan, and my sister Jenan — you are the light in my darkest moments, the purest love in my life, and the support system I never doubt. You are the solid shoulder I always lean on and the bond that strengthens me.

A special dedication to Faisal, who has been more than a brother — a pillar of strength, my companion in this journey, and someone whose support I'll never forget.

To my dearest friend Amal, your presence was always near despite the distance. You never hesitated to listen, comfort, and uplift me — thank you for being my steady soul.

And finally, I thank myself—for enduring with strength, for believing in my path, and for reaching this point despite every emotional, physical, and mental challenge.

I dedicate this to every soul with a dream, to everyone who's ever felt tired but kept going. I want you to know—one day, you'll get there too. Just like I did.

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Introduction:

Resin-based composite materials play a fundamental role in modern restorative dentistry, which allows for replicating natural teeth's physical and optical properties.[1] These materials, typically cured with visible light, are used in direct and indirect restorations for anterior and posterior dentition.[2] The development of composite materials has evolved significantly, overcoming many challenges, such as poor wear resistance and color stability in early formulations. The integration of nanotechnology has further propelled the field, resulting in the development of nano-filled composites that exhibit improved mechanical properties and overall performance.[3]

The layering technique is frequently utilized in composite insertion for two main reasons. Firstly, due to the limited light penetration in the material, composites must be light-cured in increments. Secondly, to reproduce the natural appearance of teeth, clinicians often rely on using multiple composite layers with varying shades and translucencies, making incremental placement essential in esthetically demanding restorations.[2,4] It is recommended to place light-activated resin-based composite restorations incrementally, with each increment not exceeding 2 mm in thickness, to control shrinkage and ensure thorough polymerization.[4,5] Polymerizing resin-based composites exceeding 2 mm in thickness with light-curing units can be highly unpredictable, leading to inferior physical properties, retention failures, increased solubility, and adverse pulpal responses to unpolymerized monomers.[4,5] Studies have demonstrated that bulk-fill restorations can generate considerable polymerization shrinkage stress, leading to measurable cuspal deflection and debonding at the restoration–tooth interface.[6,7]

Proper light curing of resin-based composites is a fundamental requirement during their placement. Unfortunately, the role of the dental light curing unit is often misunderstood and undervalued in many dental practices.[8] There is a recognized need for training and guidance in this essential aspect of primary dental care. It is crucial to match the energy and spectral requirements of the resin-based composites with the output from the light curing unit to achieve optimal polymerization while limiting excessive temperature increases within the pulp chamber.[8,9] Numerous studies indirectly suggest that under-cured resins significantly contribute to restoration failure, leading to fractures, secondary caries, or excessive wear.[10] Furthermore, suboptimal curing of resin-based composites, resulting in insufficient monomer conversion, increases the likelihood of leaching toxic substances.[1,8] Additional light application may contribute to improved polymerization and reduced discoloration of composite restorations.[11] However, arbitrary increases in light exposure times to prevent under-curing can lead to potential damage to the pulp and surrounding oral tissues, as light curing induces temperature elevation in these areas. Therefore, a careful balance must be maintained to ensure effective polymerization without causing harm to the tooth and surrounding tissues.[8]

The degree of conversion (DC) of resin-based cement is critical in determining its polymerization efficiency, mechanical properties, and long-term stability.[12,13] The DC refers to the extent to which the monomers in the material are transformed into a polymer network during the polymerization process.[14,15] This conversion directly influences the material's physical and mechanical properties, including its bond strength, wear resistance, and color stability.[12,14] Achieving a high degree of conversion is crucial to ensuring optimal physical properties and sustained long-term clinical performance.[12,15] Furthermore, the ideal timing for activating various composite materials remains uncertain.[12,16] There is a belief that extended exposure to light results in higher degrees of conversion.[13,14] Moreover, residual solvents in dentin bonding agents may interfere with this process by diluting the reactive monomer mixture and increasing the physical separation between monomers, reducing the formation of an effective polymer network.[15] Despite the idea that prolonged light exposure can enhance conversion, the presence of these solvents can counteract the benefits of extended irradiation, leading to lower overall conversion rates..[12,14]

Over the past two decades, numerous resin-based composites have been introduced, but some exhibit excessive tackiness, impeding easy manipulation and insertion into preparations and adhering readily to composite instruments.[2,5] Clinicians have addressed this issue by employing various lubricants, including isopropyl alcohol, acetone, dentin/enamel adhesive, and commercial products, to reduce stickiness.[2] However, the viscous nature of some composite materials, stemming from the presence of viscous monomers, has been a persistent challenge.[1,4]

The viscous consistency of composite materials during insertion and condensation can complicate clinical handling and hinder proper anatomical contour modeling and adaptation to cavity walls, increasing the risk of poor adaptation, voids, and porosity.[5,17] To address this, some clinicians have adopted the practice of lubricating instruments with modeling resins, bonding agents, or alcohol, although this deviates from manufacturers' recommendations due to the potential alteration of composite material characteristics.[1,2,5,17] Beyond improving clinical handling, using lubricants during composite modeling also plays a critical role in achieving optimal esthetic outcomes, which are essential for patient satisfaction.

Achieving patient satisfaction with dental restorations heavily relies on aesthetic considerations. Composite restorations, known for their superior aesthetic qualities compared to traditional amalgam, benefit significantly from improvements in shade matching and layering techniques.[18] Composite modeling using lubricated instruments or brushes is particularly beneficial in the esthetic region, facilitating the replication of correct anatomical form and proper surface texture during application.[19,20] This enhances esthetic outcomes and reduces the time required for contouring and finishing the restoration.[20,21] However, the composition of these materials, including monomer hydrophilicity and the presence of solvents, may influence the color stability of the final restoration.[18–21]

Although the use of instrument lubrication techniques is widely spread, there is a lack of official descriptions in scientific literature and an absence of standardized research methods for analyzing this topic.[1] Some authors like Holmes et al. and Dunn et al. are avoiding this practice, arguing that it might have the potential to incorporate foreign substances to disrupt the composition and influence the properties of the modeled composite layer.[5,15] Therefore, further research is needed to establish standardized methods and assess the impact of instrument lubrication on the performance and characteristics of dental composites.[1,2,5,17]

The optical appearance of composite restorations should remain stable over time. However, Tuncer et al. found that applying a superficial layer of modeling resin negatively affected the color stability of resin composites. Modeling liquids can reduce or delay staining when present between resin composite layers. Color shade and translucency are particularly susceptible to modification over time, requiring special attention to restorations prepared using modeling liquids.[19,20] While adhesives can serve as modeling liquids, concerns exist about the potential adverse effects of hydrophilic monomers and solvents on color stability. The hydrophilic characteristics of these components may make restorations more prone to absorbing staining pigments and changing color. Non-solvated and more hydrophobic resin adhesives, such as those found in three-step or two-step adhesive systems, are preferable as modeler liquids, as they have shown satisfactory results in previous studies. However, the increasing popularity of simplified universal adhesives raises questions about their suitability as modeling liquids for composite restorations, and further research is needed in this area.[1,20–22]

Color stability is a crucial quality for restorative dental materials because daily dietary pigments can alter these materials' external and internal appearance.[23]Tuncer et al. investigated how lubricating instruments with a modeling resin influenced the color change of composite restorations. Their findings indicated that after thermocycling, both Filtek Ultimate and Filtek Silorane composites exhibited noticeable color alterations; however, only the Filtek Silorane samples surpassed the acceptable clinical threshold for discoloration.[24] Additionally, research has shown that certain composites, namely Clearfill Majesty, Aelite LS Posterior, and Aelite All-Purpose Body, experience less color change compared to control groups, suggesting that their formulation may offer enhanced resistance to discoloration over time.[21,22] Furthermore, evidence indicates that using some adhesive systems for instrument lubrication can lead to more significant color change after water storage, highlighting the importance of selecting adhesive materials that favor long-term color stability.[20]

Interest in color research in dentistry has grown significantly over recent decades, paralleling technological advancements, computing, and communication. These developments have also driven progress in modern dentistry. In the past half-century, new technologies have emerged to enhance dental shade analysis, communication, and verification. However, shade determination for direct and indirect restorations remains a challenge, as noted by Clark in 1931 in Color Problems in Dentistry.[25] Due to the limitations of subjective visual shade selection, which often lacks standardized conditions and reliable methods, researchers have sought objective approaches to quantifying tooth color. This involved addressing color challenges in dentistry and emphasizing the critical role of light quality and quantity in accurate shade analysis.[25,26] By the late 1990s, dentistry saw its first commercial instrument-based color matching devices, beginning with the Shade Scan system designed to standardize and streamline shade communication, reproduction, and verification in esthetic restorations.[27]

Color measurement tools in dentistry include spectrophotometers, colorimeters, and digital imaging systems. Spectrophotometers are highly accurate and measure light reflectance across the visible spectrum, providing detailed color data. They are beneficial for matching tooth shades and can be keyed to dental shade guides. Spectrophotometers like CrystalEye and Vita Easyshade Compact offer advanced features such as complete tooth surface color mapping and multiple measurement modes, enhancing their clinical utility for direct and indirect restorations.[27] Spectrophotometers are widely used in dental research for color analysis due to their high accuracy and precision in measuring tooth color. They provide objective and reproducible data for achieving aesthetic outcomes in dental restorations.[28] They offer the highest accuracy and precision among shade selection methods, making them ideal for precise color matching in dental applications. Unlike visual methods, spectrophotometers reduce subjectivity and variability by providing objective color measurements.[29–31] These devices can measure the complete tooth surface, offering a detailed "color map" or an average color of a specific area, which is crucial for direct and indirect restorations.[27] Additionally, spectrophotometers ensure consistent results across measurements, which is vital for tracking color changes over time.[32,33] Advanced models integrate scientific data, like CIELAB color coordinates, aiding in precise shade reproduction in ceramic work.[34,35] Studies have shown spectrophotometers to be more reliable and reproducible than traditional shade guides, making them a preferred choice in clinical settings.[31]

The CIELAB system, developed by the Commission Internationale de l'Éclairage (CIE) in 1976, is a widely used color measurement system designed to create a uniform color space. It is based on three coordinates: L*, a*, and b*. The L* coordinate represents lightness, while a* and b* represent the green-red and blue-yellow axes. [36,37] This system transforms spectral energy data into meaningful color information and is the foundation for measuring color and color differences. In contrast, the Munsell color order system organizes colored chips for visual color matching across three dimensions: value (V), hue (H), and chroma (C). The L* value in the CIELAB system corresponds to the value (V) in the Munsell system, while the a* and b* values can be used to calculate metric chroma ($C^*ab = \sqrt{(a^2 + b^2)}$) and hue angle ($hab = \tan^{-1}(b/a)$), as defined by the CIE in 1986.[36,37]

In dentistry, the CIELAB system is commonly utilized for color measurement, relying on the three dimensions of the color space: lightness (L*) and the chromaticity coordinates a* (red/green axis) and b* (yellow/blue axis). Reductions in these parameters indicate darker, greener, and bluer colors, respectively. This system quantifies color changes, such as those resulting from staining or bleaching procedures, by calculating ΔEab. [20,24]The just noticeable difference (JND), or 50:50% perceptibility threshold (PT), for ΔE* (CIELAB ΔEab), is approximately 1.0 — that is, half of the observers will detect a color difference when ΔEab ≥1.0. The 50:50% acceptability threshold (AT) for ΔEab is about 2.7 — half of the observers consider differences above this level unacceptable.[38]

Significance:

This study addresses a clinically relevant concern in restorative dentistry: the impact of bonding agents used as lubricants on the long-term esthetic performance of composite restorations. While lubricant use is widespread among clinicians to improve handling during composite layering, its influence on color stability has not been thoroughly evaluated under controlled conditions.

By comparing the discoloration effects of common staining agents—water, coffee, and red wine—on composites treated with different lubricants, this research provides valuable evidence for selecting materials that maintain esthetic outcomes over time. The finding that bonding agents used as lubricants did not impair color stability, often performing similarly to or better than the control group, supports their potential use in clinical situations where esthetic outcomes are a priority.

Furthermore, the study contributes to the standardization of protocols for evaluating composite color stability and supports the need for careful material selection based on both functional and esthetic performance. It also lays the groundwork for future research exploring long-term clinical behavior and polymer chemistry interactions with lubricants.

Aim and Hypothesis:

The primary objective of this study is to investigate the impact of bonding agents utilized as lubricants on the color stability of composite restorations. The research aims to assess whether the choice of bonding agents employed as lubricants during composite restoration procedures influences the development of color change on the restorative material.

Alternative Hypothesis: There is a statistically significant difference in the color stability of composite restoration when various bonding agents are used as lubricants during the restorative procedure.

Materials and Methods:

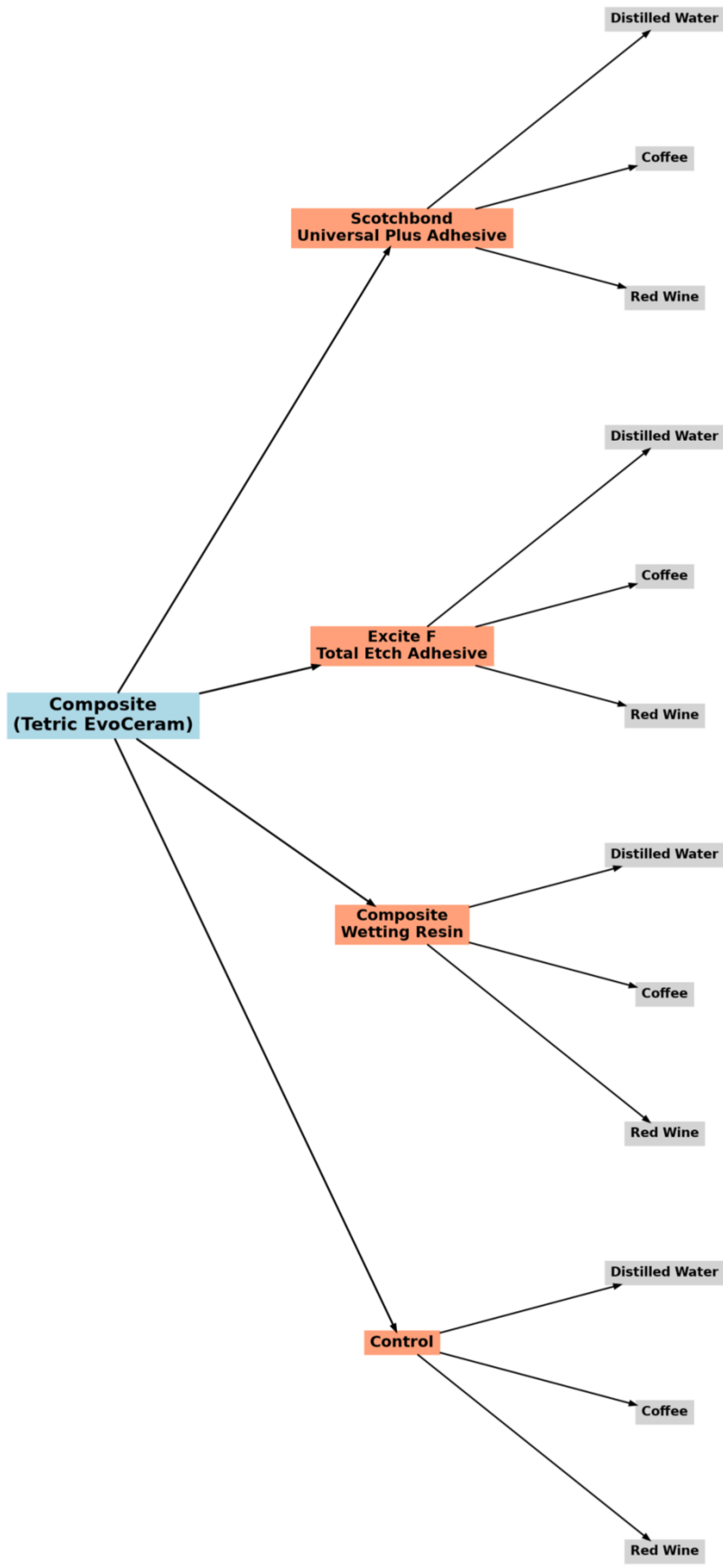
Samples preparation

Our in vitro study used resin composite specimens Tetric EvoCeram (Ivoclar Vivadent AG, Schaan/Liechtenstein) shade A2 with or without a lubricant agent to investigate the effect on color stability of the composite. The following universal adhesive systems were tested: Scotchbond Universal Plus Adhesive (3M Deutschland GmbH, Neuss, Germany), Excite F DSC Dual-Curing dental adhesive (Ivoclar Vivadent AG, Schaan/Liechtenstein), and Composite Wetting Resin, (Ultradent Products.INC, South Jordan, Utah, USA). The Specimen was fabricated by designing the shape on the TinkerCad 3D design website, and it was created using a base that contained 10 circles, 6 mm in width and 3mm in height (Figure 1, 2). The design was saved into an STL file and printed in Resin using the Formlab3+ printer. After the 3D model was created, a light body impression material (3M ESPE imprint™) light body, 3M Deutschland GmbH, Neuss, Germany) was used to fabricate a silicon mold for the composite specimens. Then, mold was used to layer the composite and fabricate the specimens. Four molds were fabricated, so each hole in each mold was used to create no more than three samples to guarantee the size and avoid any distortion or discrepancy in the mold. Each Specimen was 6 mm in width and 3 ± 0.5 mm in thickness (Figure 3). A total of 120 specimens were prepared according to the experimental groups based on the type of lubricant agent used, including a control group with no lubricant. The following protocol was followed for specimens with lubricant agents. After placing the first composite increment, a standardized drop of the corresponding lubricant agent was applied to the surface of the plastic filling instrument using a micropipette. The disposable tip was attached to the micropipette (Figure 5), which aspirated a defined volume (20 microliter) of the lubricant agent and dispensed a controlled drop onto the instrument. The instrument was then used to shape the composite increment. This process was repeated for each subsequent increment, applying the bonding agent before modeling until the third and final increment was placed.

Samples were light cured with an LED light curing unit (Coltolux LED/ Coltène/Whaledent Inc) with 1000 mW/cm^2 for 20 seconds for each increment, then 40 seconds after the placement of the last increment. The same procedure was followed in the control group, except that no lubricant agent was applied to the instrument during composite placement.[20] After light activation, all specimens were polished with medium, fine, and extra-fine aluminum oxide abrasive disks (Shofu INC. Shofu Dental Corporation, San Marcos, California, USA) for 15 seconds per disk. An electronic caliper measured the thickness of the Specimen. A single operator performed the entire specimen preparation process.

Staining process

After polishing, the specimens were randomly allocated into three groups (n = 10) according to the storage media: distilled water (Pure Life) pH 5.9, coffee (Dunkin Donuts original blend), and red wine (Robert Mondavi Woodbridge Cabernet Sauvignon). The media were renewed weekly, and specimens were kept at 37 °C for 4 weeks.


Composite
(Tetric EvoCeram)
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Color measurement

Color tests were performed following ISO/TR 28642:2016 standards. Specimens were tested under the same environmental conditions, light, and humidity from the first to the last measurement procedure. The color parameters of each Specimen were recorded according to the CIE L*a*b* system (L*: white/black; a*: red/green; b*: yellow/blue) against a black background. Measurements were obtained using a digital spectrophotometer VITA Easyshade® V (VITA Zahnfabrik H. Rauter GmbH & CO. KG Spitalglasse 3.79713 Bad Sackingen. Germany)(Figure 6), and all specimens were evaluated at different periods: immediately after polishing and storing in distilled water for 48 hours (sample preparation baseline) and after 2 and 4 weeks of storage in each medium. Each Specimen was washed with water for 10 seconds, dried with clean tissue, and then measured three times; the mean values were recorded for the three color parameters L, a, and b. Color change (ΔE*) was calculated according to the following formula: $\Delta E^* = \sqrt{(\Delta L)2 + (\Delta a)2 + (\Delta b)2}$ where ΔL*, Δa*, and Δb* are the differences between the final and initial L*, a*, and b* color parameters, respectively. ΔE* were measured after 2 and 4 weeks of storage in each medium.

Statistical Analysis:

Sample size calculations were performed in nQuery Advance. For water, the following assumptions were used: a type I error of 0.0167; a type II error of 20%; a group 1 mean (SD) of 2.0 (0.2), a group 2 mean (SD) of 3.1 (0.8), and a group 3 mean (SD) of 3.1 (0.6).21 The minimum sample size was determined to be 9 per group (groups 2 and 3 are too close to be used in the power calculations).

When comparing bonding agents treated with red wine, the sample size calculation was made assuming a type I error of 0.0167; a type II error of 20%; a group 1 mean (SD) of 20.2 (1.3), a group 2 mean (SD) of 13.2 (2.0), and a group 3 mean (SD) of 20.6 (5.4).21 For red wine, the minimum sample size was determined to be 9 per group. The sample size was increased to 10 per group to increase the power of each comparison to be over 80%.

Descriptive statistics (means and standard deviations, medians, and interquartile ranges) were calculated. For each treatment, differences in mean ΔE were compared between bond agent groups with one-way ANOVA and Tukey's HSD. The Kruskal-Wallis test with Dunn's test and the Bonferroni correction were used if the data was not normally distributed. Welch's ANOVA was used if the variances were unequal. The normality of the data was assessed graphically and with the Shapiro-Wilk test. The equality of variances was examined using Levene's test. Paired t-tests were used to compare delta E for each group between time points. P-values less than 0.05 were considered statistically significant unless the Bonferroni correction was applied. SPSS version 29 was used for the analysis.

Results:

Table 3. Mean ΔE at 2 Weeks (One-Way ANOVA with Post Hoc Analysis)

Product	Water ΔE (Mean ± SD)	Coffee ΔE (Mean ± SD)	Wine ΔE (Mean ± SD)	p-value
Control	1.07 ± 0.30	8.29^{A} ± 1.07	10.15^{A} ± 2.98	<0.001
Scotchbond Universal	0.95 ± 0.40	6.87^{A} ± 1.03	9.54^{A} ± 4.33	<0.001
Excite F	0.82 ± 0.24	7.14^{A} ± 0.95	8.29^{A} ± 2.79	<0.001
Wetting Resin	1.09 ± 0.40	6.59^{A} ± 1.39	7.96^{A} ± 3.03	<0.001
p-value	0.291	0.010	0.425	

*means sharing a letter in the same row are not statistically significant at the 5% level of significance

After two weeks (Table 3)

All groups exhibited minimal color change in water, with ΔE values below the perceptibility threshold (ΔE < 3.7). Although the overall ANOVA is not significant (p = 0.291), the lowest ΔE was observed in the Excite F group (0.82 ± 0.24), followed by Scotchbond Universal (0.95 ± 0.40), control (1.07 ± 0.30), and Wetting Resin (1.09 ± 0.40), indicating good color stability in a neutral medium.

In the coffee group, all materials showed clinically perceptible discoloration (ΔE > 3.7) and significantly reduced staining (overall p = 0.010). The Control group exhibited the highest color change (8.29 ± 1.07), whereas Wetting Resin showed the lowest (6.59 ± 1.39), followed by Scotchbond Universal (6.87 ± 1.03) and Excite F (7.14 ± 0.95). The control group has a statistically significant difference with Scotchbond Universal and Wetting Resin. Similarly, in the wine group, the Control group demonstrated the most significant discoloration (10.15 ± 2.98), with progressively lower ΔE values for Scotchbond Universal (9.54 ± 4.33), Excite F (8.29 ± 2.79), and Wetting Resin (7.96 ± 3.03). However, the overall ANOVA is not significant ($p = 0.425$).

Table 4. Mean ΔE at 4 Weeks (One-Way ANOVA with Post Hoc Analysis)

Product	Water ΔE (Mean ± SD)	Coffee ΔE (Mean ± SD)	Wine ΔE (Mean ± SD)	p-value
Control	1.51 ± 0.38	10.61 ± 1.62	14.69 ± 3.80	<0.001
Scotchbond Universal	1.24 ± 0.33	9.09 ± 1.49	14.00 ± 5.45	<0.001
Excite F	1.30 ± 0.37	9.64^{A} ± 1.01	12.50^{A} ± 3.38	<0.001
Wetting Resin	1.39 ± 0.22	9.19^{A} ± 1.56	11.82^{A} ± 4.33	<0.001
p-value	0.289	0.289	0.430	

*means sharing a letter in the same row are not statistically significant at the 5% level of significance

After four weeks (Table 4)

The total ΔE values remain low, and the overall differences among products were not statistically significant ($p = 0.289$) in water. While in coffee, the control continues to have the highest value. Although all groups exhibit increased ΔE compared to 2 weeks, group differences are not statistically significant ($p = 0.289$). Correspondingly, in wine, the control records the highest ΔE

(14.69), while Wetting Resin provides the most stable product (the lowest ΔE of 11.82). Nonetheless, the overall ANOVA is not significant ($p = 0.430$).

Table 5. Mean Increase in ΔE from 2 to 4 Weeks (Paired t-Test)

Product	Water ΔE Increase	Coffee ΔE Increase	Wine ΔE Increase
Control	+0.44	+2.32	+4.54
Scotchbond Universal	+0.29	+2.22	+4.46
Excite F	+0.48	+2.50	+4.21
Wetting Resin	+0.30	+2.60	+3.86

Time Effect on Color Change (Table 5)

Paired t-tests indicate that all products exhibit a statistically significant increase in ΔE from 2 to 4 weeks.

The absolute increase is minimal for water (≈0.3–0.5), moderate for coffee (≈2.2–2.6), and highest for wine (≈3.9–4.5).

Although the control shows the highest ΔE at both time points, the bonding agents decreased the initial discoloration and slowed the progression over time, especially under wine conditions.

Table 6. ΔE at 2 weeks, 4 weeks, and the change in ΔE between 2 and 4 weeks

		ΔE - 2 Weeks		ΔE - 4 Weeks		Change in ΔE between 2 and 4 weeks	
Stain	Product	mean ± SD	p-value	mean (SD)	p-value	mean	p-value
Water	Control	1.07 ± 0.30	0.29	1.51 ± 0.38	0.29	0.44	< 0.001
	Scotch Bond	0.95 ± 0.40		1.24 ± 0.33		0.29	0.03
	Excite F	0.82 ± 0.24		1.30 ± 0.37		0.48	< 0.001
	Wetting Resin	1.09 ± 0.40		1.39 ± 0.22		0.3	0.03
Coffee	Control	8.29^{B} ± 1.07	0.01	10.61 ± 1.62	0.09	2.32	< 0.001
	Scotch Bond	6.87^{A} ± 1.03		9.09 ± 1.49		2.22	< 0.001
	Excite F	7.14^{AB} ± 0.95		9.64 ± 1.01		2.5	< 0.001
	Wetting Resin	6.59^{A} ± 1.39		9.19 ± 1.56		2.6	< 0.001
Red Wine	Control	10.15 ± 2.98	0.43	14.69 ± 3.80	0.43	4.54	< 0.001
	Scotch Bond	9.54 ± 4.33		14.00 ± 5.45		4.46	< 0.001
	Excite F	8.29 ± 2.79		12.50 ± 3.38		4.21	< 0.001
	Wetting Resin	7.96 ± 3.03		11.82 ± 4.33		3.86	< 0.001

*Means sharing a letter are not statistically significant at the 5% level of significance

Comparison at 2 and 4 weeks with changes (Table 6)

Significant color change over time was observed in most material-stain combinations, especially in coffee and wine staining. The data indicate that the severity of color change increases from water to coffee to wine. The untreated control consistently shows the highest ΔE values, particularly for coffee and wine stains, whereas the lubricating agents reduce staining intensity. At 2 weeks, statistically significant differences ($p < 0.05$ or lower) are evident among products under coffee and wine conditions. By 4 weeks, although ΔE values increase for all groups, the differences among lubricating agents' groups become statistically non-significant.

These findings directly address the study's primary objective of assessing whether the choice of lubricating agent influences the color stability of composite restorations.

The results support the alternative hypothesis by demonstrating that at least at the 2-week time point, there are statistically significant differences in color stability among the groups. In particular, for aggressive staining agents (coffee and wine), lubricating agent agents, especially Wetting Resin, provide superior color stability compared to the control group with no treatment. However, by 4 weeks, the differences are less pronounced, suggesting that the lubricating agent's effect is not significant over time.

The choice of bonding agent significantly influenced color stability under coffee staining conditions but had minimal impact in water and wine. ΔE values increased substantially over time in all groups, with coffee and wine causing the most significant color instability. The following interaction plots show the differences between the four groups.

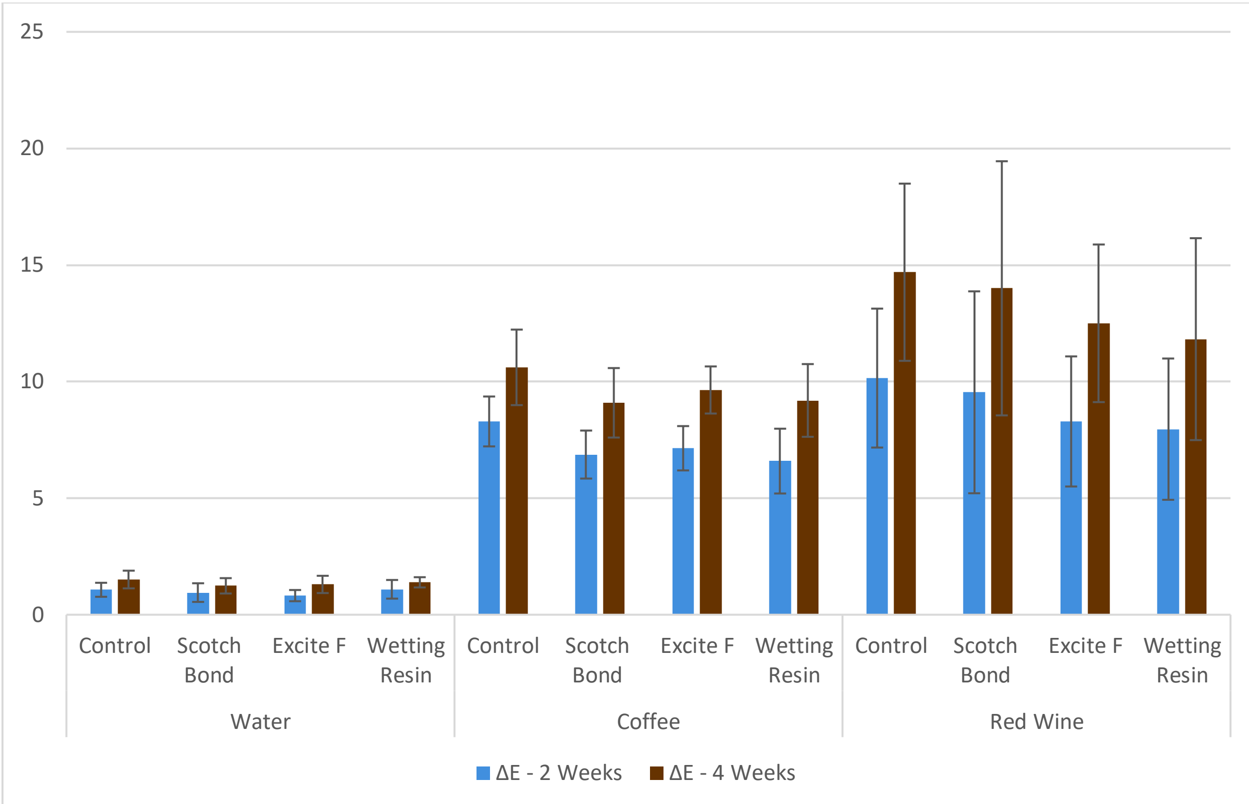

Figure 7. ΔE at 2 weeks and 4 weeks stained with water, coffee, or red wine.

Interaction plots were created to show the differences between the four groups at 2 and 4 weeks under each staining condition:

- Water Staining: All groups stayed below the perceptibility threshold, showing excellent color stability over time.

- Coffee Staining: A clear difference is seen between groups at 2 weeks, especially between the Control and Wetting Resin. By 4 weeks, the gap narrows.

- Wine Staining: All groups exhibit the highest ΔE increases, with Wetting Resin consistently maintaining the best performance

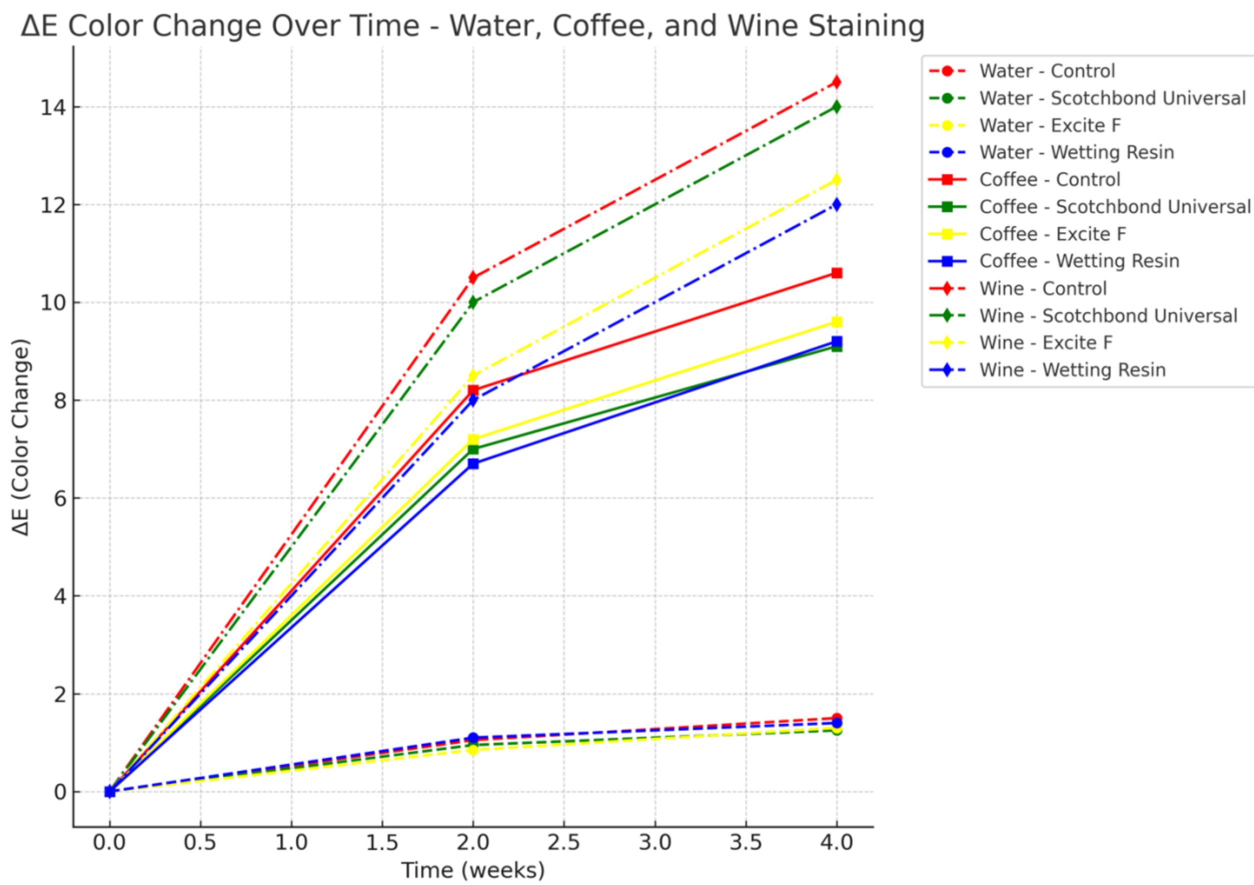

Figure 8. Interaction plot for the 4 four tested materials under the three stain solutions.

Discussion:

The primary objective of this study was to investigate whether using lubricant agents during composite restoration procedures influences the composite restorative material's color stability when exposed to staining agents. The null hypothesis was rejected at the two-week evaluation time, where significant differences in color stability were observed among groups. However, at four weeks, the lack of significant differences leads to partial rejection of the null hypothesis, indicating that the effect of bonding agents on color stability is less pronounced over time.

Staining Agents and their time dependent effects on Color Stability

Our results demonstrated that the severity of color change increased from water to coffee to wine. This finding is consistent with the established literature by Melo et al. and Tuncer et al., indicating that aqueous solutions cause minimal discoloration. In contrast, more chromogenic agents, such as coffee and wine, induce more significant changes.[23,24] Münchow and Catelan described the wine as an aggressive staining agent due to its high content of chromogenic pigment, which can enhance the penetration and chemical interaction with the resin matrix.[20,39] The cumulative effects of prolonged exposure to staining solutions resonates with observations by Sarrett et al. and Barutcigil et al., who reported increased composite degradation and wear in alcoholic solutions due to ethanol's plasticizing effect, leading to increased porosity and susceptibility to staining. This underscores that the ethanol in beverages like wine may partially account for the increased staining susceptibility observed in this study.[40,41] In contrast, studies by Yazkan et al. and Ceci et al. found that coffee caused more staining than Coke and red wine.[42,43] Although the study time was equivalent to our study, this disagreement may be due to the difference in coffee concentration, the type of composite materials, and their composition.

Paired t-tests comparing ΔE values between 2 and 4 weeks confirmed that all groups experienced a significant increase in color change over time. The magnitude of the increase was minimal for water (approximately +0.3–0.5), more pronounced for coffee (approximately +2.2–2.6), and even more for wine (approximately +3.9–4.5). These observations emphasize the critical influence of both time and the nature of the staining agent on composite discoloration, confirming findings from Santos-Melo et al. and Münchow et al., who observed that aging accentuates color change in composite materials.[20,23] There is a lack of data to link the staining time in our study and clinical scenarios.

Effect of Bonding Agents and Composite Composition

In our study, the untreated Control group consistently exhibited the highest ΔE values for both coffee and wine stains, confirming that the absence of a bonding agent leads to inferior color stability, which coincides with the study of Araujo et al.[22]

At two weeks of evaluation, one-way ANOVA with Games–Howell post hoc tests revealed statistically significant differences among the products for coffee staining ($p = 0.010$) and a trend for wine staining ($p = 0.425$). In contrast, water staining differences were insignificant ($p = 0.291$). Specifically, under water staining, although the overall ANOVA did not reach significance, post hoc analyses indicated that the Excite F produced the lowest ΔE (0.82 ± 0.24), suggesting better performance in maintaining color stability in aqueous environments, which corresponds with the findings of Münchow et al. and Sedrez-Porto et al.[20,21]

The control group showed a markedly higher ΔE (8.29 ± 1.07) for coffee staining than those treated with lubricating agents. The observed pattern showed that the Control group exhibited the highest discoloration, followed by Excite F, while Scotchbond Universal Plus and Wetting Resin demonstrated comparable and lower staining levels. Similarly, for wine staining, the control presented the highest ΔE (10.15 ± 2.98), while Wetting Resin produced the lowest ΔE (7.96 ± 3.03), indicating superior efficacy in reducing discoloration. These findings align with previous reports documenting the beneficial effects of specific lubricant agents in reducing discoloration when used as modeling liquids.[20,21]

At four weeks of evaluation, although the ΔE values increased for all groups, the overall differences among the products were not statistically significant (water: $p = 0.289$; coffee: $p = 0.289$; wine: $p = 0.430$), which suggests that the initial differences observed may be stabilized over time.[22,24] For example, under coffee staining conditions, the ΔE for the control group increased to 10.61 ± 1.62, while the groups treated with bonding agents showed ΔE values ranging from 9.09 ± 1.49 to 9.64 ± 1.01.[22] Similarly when exposed to wine staining. However, the control group reached a ΔE of 14.69 ± 3.80, and the group treated with the wetting Resin exhibited the lowest mean ΔE of 11.82 ± 4.33.[22] These not significant differences by four weeks indicate that although this study was standardized, it is difficult to reproduce the clinical scenarios.

Literature Integration and Clinical Implications

Although studies by Maia et al. and Mundim et al. have shown that toothbrushing can significantly reduce discoloration through mechanical abrasion, these findings highlight the complexity of replicating clinical conditions in an in vitro setting. In real-world scenarios, factors such as saliva, dietary habits, and daily oral hygiene practices, particularly brushing can influence the degree and persistence of staining, making it challenging to directly correlate laboratory results to clinical outcomes. [44,45]

The data from the two-week immersion showed that specimens treated with Composite Wetting Resin underwent significantly less color change in coffee than untreated controls ($p < 0.05$).[46,47] By 4 weeks, however, ΔE values for treated and control groups converged, indicating that the initial color stability of the wetting Resin reduces with prolonged exposure to staining agents.[48] These findings suggest applying a lubricant agent during composite placement can enhance shade stability.[46,47] While the results do not directly translate to in vivo conditions, they provide valuable insight that supports continued investigation into strategies to preserve the color stability of composite restorations.[48]

Our findings are consistent with prior research by Tencer et al., which demonstrated that modeling resins can affect resin composites' surface properties and color. However, the effects vary with composite type and resin composition.[24] Münchow et al. and Sadrez-Porto et al. reported that specific adhesive systems used as modeling liquids enhance the physical and optical properties of composites, with hydrophobic adhesives showing favorable outcomes.[20,21,23]

Catelan et al. and Melo et al. highlighted the importance of the degree of conversion in determining the composite's susceptibility to staining. Increased degrees of conversion result in fewer residual monomers, which reduce composite porosity and enhance resistance to pigment penetration. While reducing the degree of conversion leads to more intrinsic staining.[23,39] Cadenaro et al., in two separate studies, confirmed that the presence of ethanol in adhesive systems compromises the degree of conversion, potentially increasing susceptibility to staining. This may help explain our study's superior color stability observed with Wetting Resin, as it does not contain ethanol. [49,50]

Maia et al. concluded that wetting resin was more susceptible to stain due to its high porosity. This was not aligned with our result that wetting Resin is the least stained product, especially under wine. On the other hand, the same author confirmed with our results that scotchbond universal showed less discoloration compared to the control group.[44] Moreover, Araujo et al. and Santos-Melo et al. provided evidence that while early color stability may be improved with these techniques, long-term challenges remain due to the cumulative effect of aggressive staining agents.[22,23]

Limitations:

Several limitations should be considered when interpreting the findings of this in vitro study. First, thermocycling was not performed, which may have influenced the degree of material aging and degradation. Thermal stresses introduced through repeated temperature changes in the oral cavity could impact the composite structure and its interaction with surface treatments, potentially altering color stability over time.

Second, the staining duration used in this study was deliberately exaggerated to simulate long-term exposure within a short period. While this approach facilitates accelerated aging, it does not reflect the gradual, intermittent nature of staining in clinical environments. Therefore, the results cannot be directly extrapolated to predict clinical performance over comparable timeframes.

Additionally, the absence of key oral variables—such as saliva, diet, and mechanical forces like toothbrushing—further limits the clinical relevance of the discoloration outcomes. These factors play a significant role in stain accumulation, removal, and material degradation, and their omission highlights the artificial nature of the experimental conditions.

Lastly, water storage showed minimal staining differences within the study period; however, longer observation times may be necessary to detect more subtle or cumulative effects in this medium.

Conclusion:

This study confirmed that the type of bonding agent used as a lubricant significantly affects the color stability of composite restorations, especially under staining conditions. Wetting Resin consistently showed the least discoloration among all products tested, particularly under coffee and red wine. In contrast, the Control group (no lubricant) exhibited the highest ΔE values, especially when exposed to wine, the most aggressive staining agent.

Although differences were statistically significant at 2 weeks, by 4 weeks, all groups showed increased ΔE values and differences between materials became less pronounced. Nonetheless, Wetting Resin maintained superior performance across time points and staining conditions, followed by Scotchbond Universal Plus and Excite F.

This study suggests that using bonding agents as lubricants during composite placement does not adversely affect color stability and may offer a protective effect under staining conditions. While these findings are limited to in vitro settings, they support incorporating this technique with composite restorations.

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APPENDIX A: Tables

Table 1. Material Used in the Study.

Product Name	Manufacturer
Tetric EvoCeram	Ivoclar Vivadent AG, Schaan/Liechtenstein
Scotchbond Universal Plus Adhesive	3M Deutschland GmbH
Excite F DSC Dual-Curing dental adhesive	Ivoclar Vivadent AG, Schaan/Liechtenstein
Composite Wetting Resin	Ultradent Products.INC, South Jordan, Utah, USA

Table 2. Staining solutions presented in the study.

Staining Solution	Manufacturer
Distilled Water	Pure life
Coffee	Dunkin Donut original blend
Red Wine	Robert Mondavi Woodbridge Cabernet Sauvignon

Table 3. Mean ΔE at 2 Weeks (One-Way ANOVA with Post Hoc Analysis)

Product	Water ΔE (Mean ± SD)	Coffee ΔE (Mean ± SD)	Wine ΔE (Mean ± SD)	p-value
Control	1.07 ± 0.30	8.29^{A} ± 1.07	10.15^{A} ± 2.98	<0.001
Scotchbond Universal	0.95 ± 0.40	6.87^{A} ± 1.03	9.54^{A} ± 4.33	<0.001
Excite F	0.82 ± 0.24	7.14^{A} ± 0.95	8.29^{A} ± 2.79	<0.001
Wetting Resin	1.09 ± 0.40	6.59^{A} ± 1.39	7.96^{A} ± 3.03	<0.001

Product	Water ΔE (Mean ± SD)	Coffee ΔE (Mean ± SD)	Wine ΔE (Mean ± SD)	p-value
p-value	0.291	0.010	0.425	

*means sharing a letter in the same row are not statistically significant at the 5% level of significance

Table 4. Mean ΔE at 4 Weeks (One-Way ANOVA with Post Hoc Analysis)

Product	Water ΔE (Mean ± SD)	Coffee ΔE (Mean ± SD)	Wine ΔE (Mean ± SD)	p-value
Control	1.51 ± 0.38	10.61 ± 1.62	14.69 ± 3.80	<0.001
Scotchbond Universal	1.24 ± 0.33	9.09 ± 1.49	14.00 ± 5.45	<0.001
Excite F	1.30 ± 0.37	9.64^{A} ± 1.01	12.50^{A} ± 3.38	<0.001
Wetting Resin	1.39 ± 0.22	9.19^{A} ± 1.56	11.82^{A} ± 4.33	<0.001
p-value	0.289	0.289	0.430	

*means sharing a letter in the same row are not statistically significant at the 5% level of significance

Table 5. Mean Increase in ΔE from 2 to 4 Weeks (Paired t-Test)

Product	Water ΔE Increase	Coffee ΔE Increase	Wine ΔE Increase
Control	+0.44	+2.32	+4.54
Scotchbond Universal	+0.29	+2.22	+4.46
Excite F	+0.48	+2.50	+4.21
Wetting Resin	+0.30	+2.60	+3.86

Table 6. ΔE at 2 weeks, 4 weeks, and the change in ΔE between 2 and 4 weeks

		ΔE - 2 Weeks		ΔE - 4 Weeks		Change in ΔE between 2 and 4 weeks	
Stain	Product	mean ± SD	p-value	mean (SD)	p-value	mean	p-value
Water	Control	1.07 ± 0.30	0.29	1.51 ± 0.38	0.29	0.44	< 0.001
	Scotch Bond	0.95 ± 0.40		1.24 ± 0.33		0.29	0.03
	Excite F	0.82 ± 0.24		1.30 ± 0.37		0.48	< 0.001
	Wetting Resin	1.09 ± 0.40		1.39 ± 0.22		0.3	0.03
Coffee	Control	8.29^{B} ± 1.07	0.01	10.61 ± 1.62	0.09	2.32	< 0.001
	Scotch Bond	6.87^{A} ± 1.03		9.09 ± 1.49		2.22	< 0.001
	Excite F	7.14^{AB} ± 0.95		9.64 ± 1.01		2.5	< 0.001
	Wetting Resin	6.59^{A} ± 1.39		9.19 ± 1.56		2.6	< 0.001
Red Wine	Control	10.15 ± 2.98	0.43	14.69 ± 3.80	0.43	4.54	< 0.001
	Scotch Bond	9.54 ± 4.33		14.00 ± 5.45		4.46	< 0.001
	Excite F	8.29 ± 2.79		12.50 ± 3.38		4.21	< 0.001
	Wetting Resin	7.96 ± 3.03		11.82 ± 4.33		3.86	< 0.001

*Means sharing a letter are not statistically significant at the 5% level of significance

APPENDIX B: Figures

Figure 1: The 3d design model.

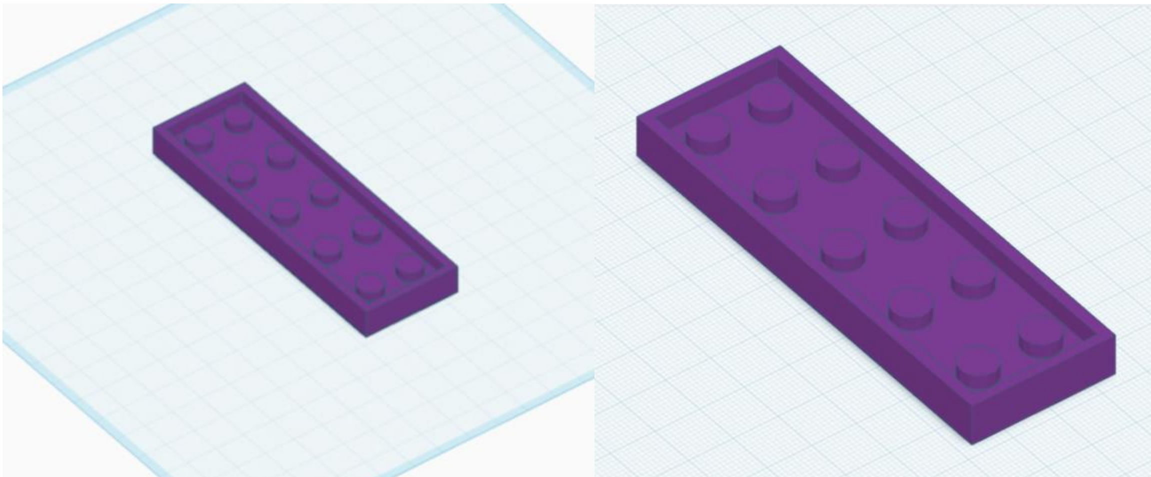

Figure 2: The printed design and the silicone mold.

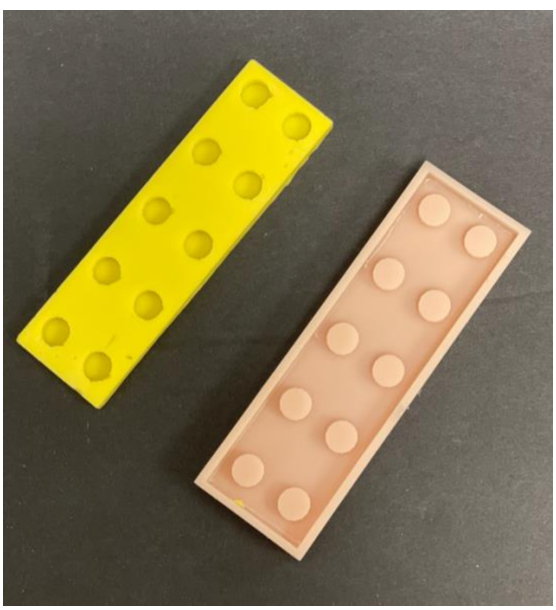

Figure 3: The sample disc with a diameter of 6mm and thickness of 3mm.

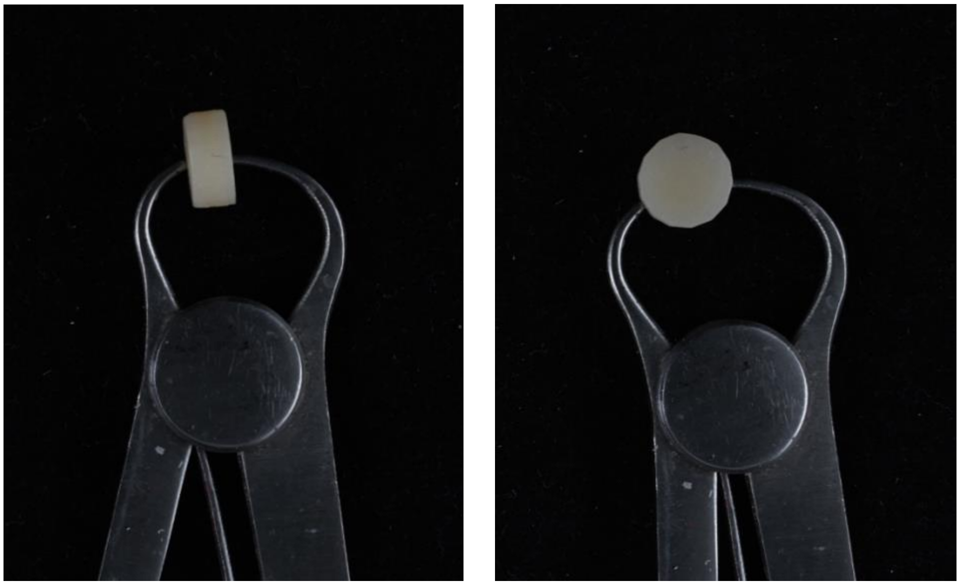

Figure 4: Kashi Scientific 1.5 mL Centrifuge Tubes.

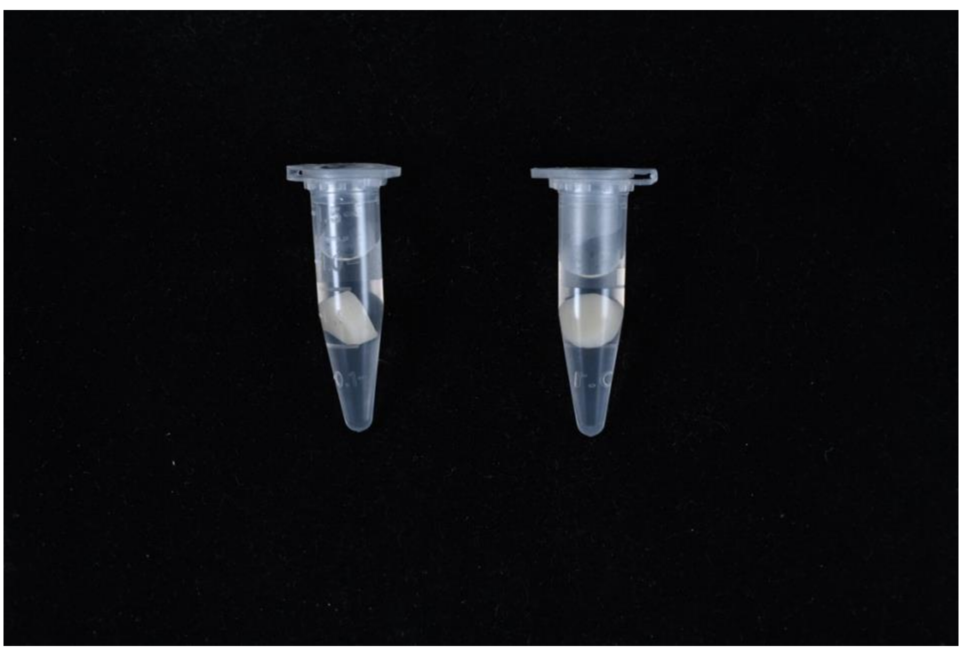

Figure 5: Micropipette.

Figure 6: Color measurements using VITA Easyshade V against a black background.

Figure 7. ΔE at 2 weeks and 4 weeks stained with water, coffee, or red wine.

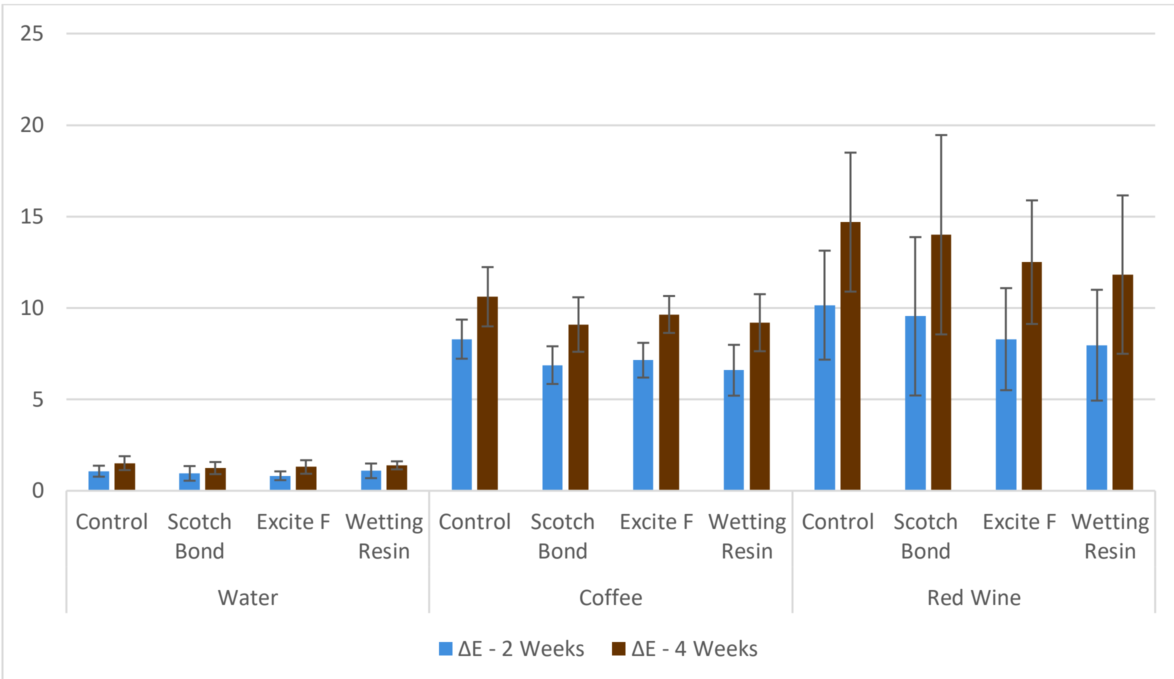

Figure 8. Interaction plots for the 4 four tested materials under the three stain solutions.