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Effect of modeling liquids on resin composite roughness and color parameters after staining and toothbrushing

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Abstract: This study evaluated surface roughness, color stability, whitening index, and opacity of different types of modeling liquids for resin composite coating after exposure to staining and toothbrushing. Disc-shaped resin composite (Vittra APS, FGM) specimens were fabricated and divided into four groups (n = 10 each): control group, Composite Wetting resin (Ultradent Products), Adper Scotchbond Multipurpose adhesive (3M ESPE), and Adper Universal adhesive (3M ESPE). Surface roughness (Ra) was measured using a rugosimeter, while color stability (ΔE_{00}), whitening index (WI), and opacity (%) were measured using a spectrophotometer. Assessments were made at four time points: after polishing (baseline, T1), after immersion in red wine for 24 h (T2), and after 5,000 (T3) and 10,000 (T4) cycles of toothbrushing. Scanning electron microscopy images were captured to analyze the scratches created. The data were statistically analyzed by two-way repeated-measures analysis of variance and Tukey's honestly significant difference tests ($\alpha = .05$). Modeling with the Wetting resin resulted in higher surface roughness ($p < 0.05$) and low color stability, which were attributable to porosities. Higher color change values were observed in the control group after staining. Both adhesives showed the lowest mean ΔE_{00} values ($p < 0.005$). WI decreased after staining, except with the use of the Universal adhesive ($p < 0.005$). The lowest opacity values were observed at baseline for all groups ($p < 0.005$). The Universal and Scotchbond adhesives had lower surface roughness, better color stability, higher WI, and the lowest opacity values after staining with red wine and toothbrushing.

Keywords: Color; Toothbrushing; Wine.

Introduction

Resin-based composites has become the most common restorative material used in anterior and posterior teeth because of its wide clinical applicability, excellent esthetics, acceptable biocompatibility, and appropriate physical and mechanical properties.[1-3] However, composites undergo constant degradation when exposed to different conditions in the oral cavity.[4,5] Changes in pH, absorption of pigments present in beverages and foods, and toothbrushing, among other factors, can cause the loss of restorative material and tooth structures.[5-7]

Surface quality of resin composites plays a significant role in maintaining the esthetic appearance of restorations. This quality is key in patients' perception of and dissatisfaction with restorations; it is also a the major reason for frequent replacement of restorations.[7-10] Many factors can lead to loss of surface quality — mainly, changes in surface color and roughness.[11,12] A rougher surface is more prone to plaque accumulation,[11] may have a deleterious effect on the wear of the antagonistic natural teeth, reflects a lesser amount of light than smooth surfaces, and increases tooth staining.[4,7,11,13-15]

Owing to an increase in patients' high esthetic demands and the pursuit of a harmonious smile, techniques and materials are continually being improved and developed, thereby enabling restorative dentists to leverage the direct composite technique.[8,9] Nevertheless, this technique has a learning curve as it requires operator skill at handling the material and the sticky consistency of several composites can hinder their placement and sculpting.[16,17] Therefore, specific low-viscosity liquids are available for relatively easy build-up restorations.[18-20] These liquids, applied during or over the last increment while building up a restoration, are beneficial to reducing tooth surface tension, which smooths the incremental layer of the resin composite, improves the surface adaptability of the composite, and fills microstructural defects, having a sealing effect.[19-22] While some clinicians have used specific liquids for modeling resin composites, the use of adhesives has gained popularity for this purpose.[19,20]

In this context, the use of a modeling liquid to increase the handling of the final composite increment can improve some of its physical properties.[20,23-25] The present *in vitro* study compared the surface roughness, color stability, whitening index (WI), and opacity of different modeling liquids subjected to erosive and abrasive challenges by staining and toothbrushing simulation to answer the following question: "Does the application of modeling resin on composite restorations maintain their optical properties after simulated degradation by combining red wine staining and toothbrushing?". The first null hypothesis was that surface roughness would not vary between the different types of modeling liquid coatings. The second null hypothesis was that staining and toothbrushing would not influence the color stability of resin composite specimens coated with modeling liquids.

Methodology

Specimen preparation

Disc-shaped specimens (8-mm ø × 1.5-mm height) were built up in a single increment of resin composite (Vittra; A2 for enamel; FGM, Joinvile, Santa Catarina, Brazil). After inserting the increment into a Teflon matrix, the excess composite was removed by moving a glass plate parallel to the surface of the matrix. A spreadsheet (Excel; Microsoft New Mexico, USA) containing random numbers was used to randomly allocate the specimens into one of the four experimental groups (n = 10 each), according to the modeling liquid used. One group served as the control (no model liquid) and three groups received a type of modeling liquid, as follows: Composite Wetting resin (Ultradent Products Inc., South Jordan, USA), Adper Scotchbond Multipurpose (3M ESPE, St. Paul, USA), or Adper Universal (3M ESPE, St. Paul, USA). The polymer matrix composition, filler characteristics, and content are displayed in Table 1.

Except for the control, the composite surface was smoothed using a brush (#4, Kota, Cotia, São Paulo, Brazil) and covered with the modeling liquid randomized for each experimental condition. The modeling liquid was applied with the brush performing six movements in the same direction to prevent the formation of porosities and to obtain a surface similar to that observed clinically. The adhesives were agitated before application and the solvent was evaporated using a gentle air blast for 5 s before light-curing. The increment was individually light-cured with a Valo LED-based unit (irradiance, 1,000 mW/cm^2; Ultradent Products Inc., South Jordan, USA) for 20 s. After storage in an incubator (Solab, Piracicaba, São Paulo, Brazil) in distilled water at 37.7°C for 24 h, the specimens were polished with a

Table 1. Description of the evaluated materials.

Material (manufacturer)	Monomers and solvents	Filler content
Vittra APS (FGM, Joinville, Brazil)	UDMA, TEGDMA	Silica-zirconia
Composite Wetting Resin (Ultradent Products Inc, South Jordan, USA)	TEGDMA, DUDMA	Silica
Scotchbond Multipurpose (3M ESPE, St. Paul, USA)	BisGMA, HEMA	-
Single Bond Universal (3M ESPE, St. Paul, USA)	MDP, dimethacrylate resins, HEMA, polyacrylic acid methacrylate copolymer, polyalkenoic acid, ethanol and water.	Silica

UDMA: urethane dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; DUDMA: diurethane dimethacrylate; TMSPM: Bis-GMA: bisphenol A glycidyl methacrylate; HEMA: 2-hydroxyethyl methacrylate; MDP: 10-methacryloyloxydecyl dihydrogen phosphate.

series of aluminum oxide discs (medium, fine and, extra-fine abrasiveness; Sof-lex, 3M ESPE, St. Paul, USA) for 20 s per disc by a single trained operator. Subsequently, each disc was washed for 20 s. Upon the conclusion of the polishing cycle, the specimens were immersed in an ultrasonic bath (Thornton, Vinhedo, Brazil) for 10 min. The final thickness of each specimen was measured using a digital caliper (Absolute AOS Digimatic, Mitutoyo, Tokyo, Japan), and specimens < 1.45 mm or > 1.55 mm were replaced. All measurements were performed at baseline (after polishing, T1), 24 h after specimen immersion in red wine (T2),[24] and after 5,000 (T3) and 10,000 (T4) brushing cycles.[13]

Surface roughness measurement

The surface roughness (Ra) of each specimen was obtained using a surface roughness tester (Surftest 301 J, Mitutoyo, Kanagawa, Japan) at a speed of 0.25 mm/s, using a cut-off of 0.8 mm. The mean value of three readings was computed and used for subsequent statistical analysis.

Measurement of color parameters

Color parameters were measured using a digital spectrophotometer (SP64, X-Rite, Grand Rapids, USA) in reflectance mode, with a D65 illuminant, and a wavelength range of 400–700 nm, including a specular light (SPIN mode), and an observer angle of 10°. The L*a*b* color system defined by the Commission Internationale de l'Éclairage (CIE) was used. This system consists of three parameters, where L* indicates lightness (black to white) and a* and b* are the chromaticity coordinates for the red-green and yellow-blue axes, respectively. The color measurements were performed in triplicate for each specimen, and the mean values were recorded as L0*, a0*, and b0*. The color parameters were measured against white ($L^*_{white} = 86.70$, $a^*_{white} = -1.17$, $b^*_{white} = 1.60$) and black ($L^*_{black} = 29.96$, $a^*_{black} = 0.42$, $b^*_{black} = 1.49$) backgrounds to obtain the opacity of the specimens, which was auto-calculated using a spectrophotometer. The device was adjusted to a small-area view, with a total area of 4 mm. The WI was calculated using the following formula:[26]

[Formula 1] $WI = 0.551 \times L - 2.324 \times a - 1.1 \times b$

Staining procedure

The specimens were embedded in transparent nail polish to cover the unpolished surfaces during the staining procedure. The specimens were immersed in plates containing 10 mL of red wine (Cabernet Sauvignon Concha Y Toro Reservado, Concha y Toro, Santiago, Chile) and kept in an incubator at 37.7 °C for 24 h.[24] The pH of the wine (2.6) was measured using a pH meter (JK-PHM-005, JKI, Shang Hai, China). After staining, the specimens were subjected to ultrasonic cleaning in distilled water for 10 min and dried before repeating the measurement of all parameters (T2).

Toothbrushing cycles

The specimens were subjected to mechanical brushing with soft-bristled toothbrushes (Colgate Essential Clean, Colgate Oral Pharmaceuticals Inc, Toronto, Ontario, Canada Inc, lot No. PBR5311687) attached to a toothbrushing simulation device

(Odeme, Luzerna, Brazil). The toothbrush heads (one per specimen) were cut off and then fitted into the clamp of the machine. The toothbrushes moved back and forth horizontally at 2.5 cm/s under a 200 g load. As 10,000 to 14,600 brushing cycles are considered equivalent to 1 year of *in vivo* toothbrushing,[13] 5,000 and 10,000 cycles were performed to simulate 6 months and 1 year of brushing, respectively. After the first 5,000 cycles, the brushes were replaced. A dentifrice (Colgate Total 12, Colgate Palmolive, Canada) was used to make a slurry (90 g of dentifrice in 180 mL of distilled water) with which the specimens were brushed. After 5,000 cycles, the specimens were subjected to ultrasonic cleaning for 10 min to remove dentifrice remnants. At the end of each set of 5,000 brushing cycles, new measurements were performed (T3 and T4).

Color changes

The overall color changes (ΔE_{00}) caused by the staining procedures and brushing cycles were calculated for T2, T3, and T4 using the following formula[27]:

[Formula 2] $$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T \frac{\Delta C'}{K_C S_C}\frac{\Delta H'}{K_H S_H}}$$

where ΔL', ΔC', and ΔH' are the changes in lightness, chroma, and hue, respectively. SL, SC, and SH are weighting functions for each component. RT is the interaction term between the chroma and hue differences. Although CIE76 (ΔE_{ab}) has been widely used in previous studies, the formula CIEDE2000 (ΔE_{00}), was chosen because it reflects the color differences perceived by the human eye better than CIE76 (ΔE_{ab}).[28]

Topographical analysis

Surface topography was analyzed, relative to smoothness and scratches, using scanning electron microscopy (EVO MA 10, Carl Zeiss, London, UK). One specimen per experimental condition was randomly selected and sputter-coated with gold/palladium for 120 s. Images were obtained at 20 kV at a working distance of 12 mm and ×5000 magnification.

Statistical analysis

The data for each outcome were individually analyzed by two-way repeated-measures analysis of variance after defining the "assessment time interval" as a repetition factor. Normal distributions and equal variances of the data were analyzed using Shapiro-Wilk and Levene's tests, respectively. Multiple comparisons were performed by Tukey's honestly significant difference tests. The significance level was set at $\alpha = 0.05$ for all analyses.

Results

Surface roughness

The results showed that only the "treatment" ($p = 0.001$) affected roughness; however, roughness remained unchanged upon evaluation by the "assessment time intervals" ($p = 0.193$). The interaction between the evaluated factors was also nonsignificant for the roughness values ($p = 0.226$) (Table 2). Irrespective of the assessment time interval, the use of Wetting resin resulted in rougher surface values compared to those yielded by the Scotchbond and Universal adhesives. Intermediate Ra values were observed for the control, without significant differences for the other treatments.

Table 2. Mean and standard deviation (SD) of Ra values according to treatment and assessment time intervalsa.

Treatment	Baseline	After staining	Toothbrushing		Pooled average
			5,000 cycles	10,000 cycles	
Control	0.31 (0.13)	0.38 (0.38)	0.79 (1.44)	0.43 (0.19)	0.48 (0.51) AB
Wetting resin	0.58 (0.23)	0.48 (0.17)	0.50 (0.25)	0.44 (0.12)	0.50 (0.14) A
Scotchbond	0.44 (0.29)	0.32 (0.16)	0.21 (0.05)	0.27 (0.05)	0.31 (0.14) B
Universal	0.34 (0.08)	0.25 (0.08)	0.28 (0.09)	0.25 (0.06)	028 (0.08) B

For pooled average, different letters indicate statistical difference shown by Tukey's test ($p < 0.05$).

Table 3. Mean and standard deviation (SD) of ΔE00 values from baseline data according to treatment and assessment time intervalsa.

Treatment	After staining	Toothbrushing	
		5,000 cycles	10,000 cycles
Control	6.48 (1.76) Aa	4.92 (2.56) Ba	4.25 (1.79) Ba
Wetting resin	4.71 (1.07) Ab	4.67 (1.53) Aa	4.16 (0.94) Aa
Scotchbond	3.86 (0.68) Ab	3.07 (0.91) ABb	2.52 (0.61) Bb
Universal	4.12 (0.15) Ab	2.61 (0.82) Bb	2.78 (1.07) Bab

Different letters (capital for line, lowercase for row) indicated statistical difference Tukey's test ($p < 0.005$).

Color parameters

Both "treatment" ($p < 0.001$) and "assessment time interval" ($p < 0.001$) affected the overall color changes (ΔE_{00}), with a significant interaction between these factors ($p = 0.009$) (Table 3). Higher color change values were observed in the control group after the staining procedure. The specimens modeled with adhesives had similar and the lowest mean color change values. Similar results were observed at T4, but the specimens modeled with the Universal adhesive showed color changes similar to those observed for the control specimens and those modeled with Wetting resin. Except in the case of the Wetting resin, toothbrushing of the specimens reduced the color changes produced by the staining procedures. However, all final values were beyond the ΔE_{00} acceptability threshold ($\Delta E_{00} = 1.77$).[29]

Figure 1 shows the color parameters measured throughout the experiment. Irrespective of treatment, a reduction in lightness of baseline values was observed after the staining procedure. In general, while toothbrushing of the specimens increased their lightness, the final values remained lower than those observed at T1. When the specimens were modeled with adhesives (highest a* values at baseline), the staining procedure increased the specimen's redness values, which were reduced by toothbrushing. A slight reduction in redness was observed in the control specimens after toothbrushing, while the a* values remained stable for specimens modeled with Wetting resin throughout the experiment. Except for the Universal adhesive, the staining procedures increased the yellowness of the specimens and produced slight changes in b* values observed after toothbrushing.

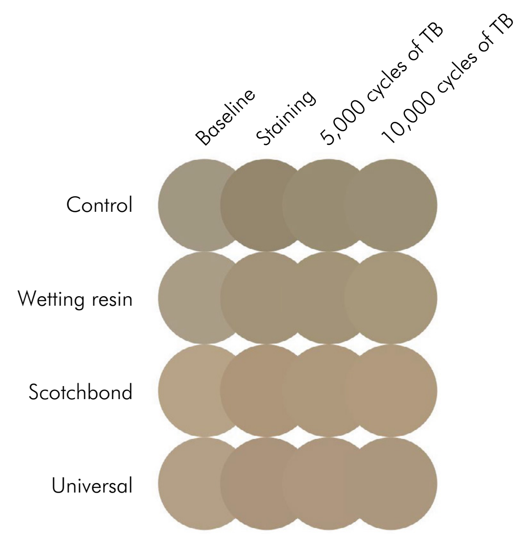

Figure 1. Behavior of color parameters according to treatment and assessment time. (A) parameter L* on the black-to-white axis, (B) parameter a* chromatic coordinates on the red-to-green axis, and (C) parameter b* chromatic coordinates on the yellow-to-blue axis.

Cylinders were drawn using CorelDraw Graphics Suite X8 (Corel Corporation, Ottawa, ON, Canada) and colored with the RGB values calculated previously to facilitate the visualization of color changes that occurred during the experiment (Figure 2). The discs in the Wetting resin group exhibited intermediate changes in color. The Scotchbond and Universal specimens were a shade lighter than the control and Wetting resin specimens (Figure 2).

Both "treatment" ($p < 0.001$) and "assessment time interval" ($p < 0.001$) affected the WI, with a significant interaction between these factors ($p < 0.001$). The WI results are presented in Table 4. Except for the Universal adhesive (stable WI), the staining procedure

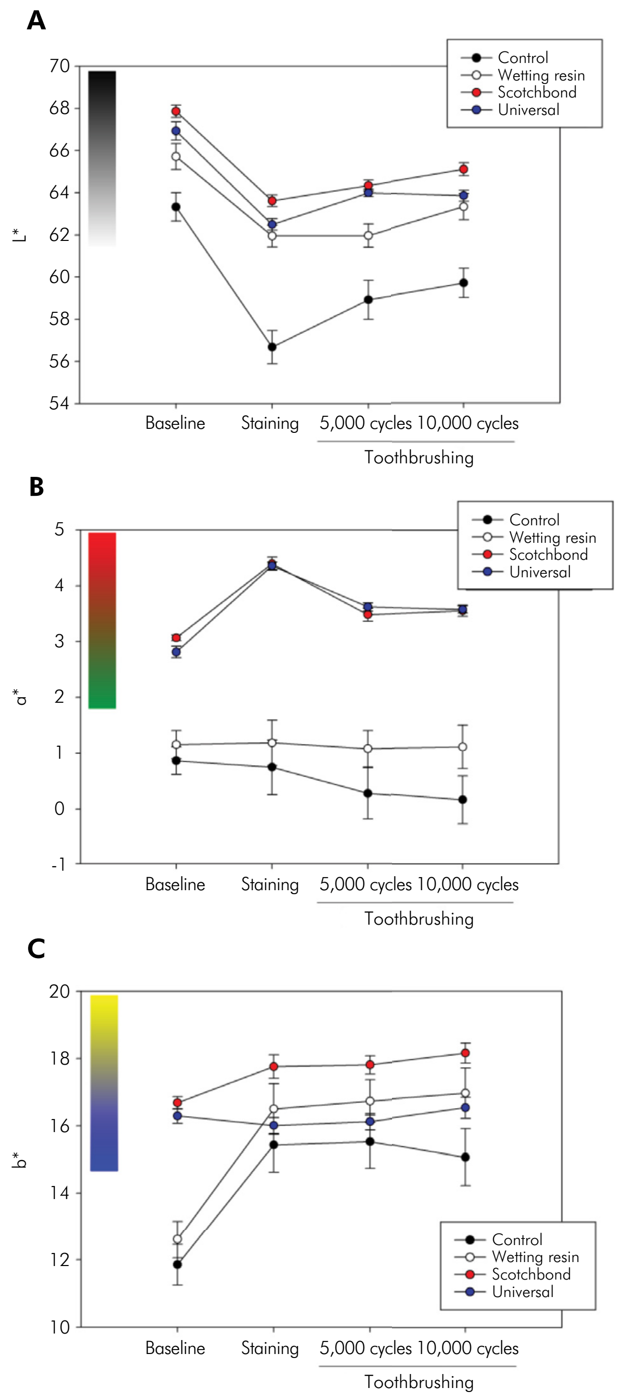

Figure 2. Illustrative disc-shaped resin composite specimens, based on data from L*a*b* converted to the RGB system.

caused a WI reduction, whereas toothbrushing cycles did not increase the WI. At other assessment time intervals, specimens modeled with the Scotchbond and Universal adhesives showed similar WI values and were a shade whiter than those that received the other treatments.

While both "treatment" ($p < 0.001$) and "assessment time interval" ($p < 0.001$) affected opacity, the interaction between these factors was not significant ($p < 0.785$) (Table 5). Irrespective of treatment, the lowest opacity values were observed at T1. Modeling the specimens with either Universal or Scotchbond adhesives resulted in more translucent specimens compared to the control specimens. The use of the Wetting resin did not change the opacity observed in the control specimens.

Topographical analysis

The scanning electron microscopy images (Figure 3) showed that the Wetting resin had the most irregular surface among the groups, observed immediately after 24 h of immersion in red wine. All groups showed some degradation, resulting in irregular surfaces, superficial scratches, and areas of debonding, after staining and toothbrushing. However, there were limited specific differences between the adhesive groups, and so it was hard to differentiate them from each other.

Discussion

The present study compared surface roughness, color stability, WI, and opacity of different modeling liquids after staining and toothbrushing challenges. In this study, all null hypotheses were rejected. The results demonstrate different degrees of color change after immersion in red wine, depending on the material. Use of the Wetting resin increased the material's susceptibility to surface roughening and color changes compared to the other adhesives. Interestingly, the staining procedure resulted in reduced roughness when a Wetting resin or an adhesive was used.[30] The ethanol content and low pH of wine led to resin matrix degradation;[31] thus, the use of a modeling liquid might help prevent this adverse effect by reducing the occurrence of porosities on the composite surface.[32]

The differences in roughness, discoloration, and other color parameters between the modeling resin and adhesives indicated the importance of

Table 4. Mean and standard deviation (SD) of whitening index values according to treatment and assessment time intervalsa.

Treatment	Baseline	After staining	Toothbrushing	
			5,000 cycles	10,000 cycles
Control	20.4 (0.8) [Aa]	12.7 (2.8) [Cc]	13.3 (2.8) [BCb]	14.2 (2.8) [Bb]
Wetting resin	21.2 (1.3) [Aa]	14.8 (1.2) [Bb]	14.5 (1.9) [Bb]	15.3 (1.3) [Bb]
Scotchbond	19.8 (0.6) [Aa]	17.3 (1.6) [Ba]	17.0 (1.4) [Ba]	17.1 (1.2) [Ba]
Universal	19.4 (0.8) [Aa]	18.9 (0.7) [Aa]	18.8 (0.8) [Aa]	18.3 (1.0) [Aa]

Different letters (capital for line, lowercase for row) indicated statistical difference Tukey's test ($p < 0.005$).

Table 5. Mean and standard deviation (SD) of opacity values according to treatment and assessment time intervalsa.

Treatment	Baseline	After staining	Toothbrushing		Pooled average
			5,000 cycles	10,000 cycles	
Control	87.7 (4.4)	90.7 (3.5)	92.2 (2.9)	91.8 (2.1)	90.6 (3.7) [A]
Wetting resin	86.1 (2.3)	87.6 (3.2)	89.5 (5.3)	88.2 (3.6)	87.9 (3.8) [A]
Scotchbond	80.9 (3.2)	83.9 (1.5)	83.5 (2.1)	83.7 (2.4)	83.0 (2.6) [B]
Universal	81.8 (1.8)	84.5 (2.0)	85.6 (2.8)	86.1 (4.2)	84.5 (3.2) [B]
Pooled average	84.1 (4.1) [B]	87.6 (3.8) [A]	87.7 (4.8) [A]	87.5 (4.3) [A]	

For pooled averages, different letters indicate statistical difference shown by Tukey's test ($p < 0.005$).

the composition of these materials.[33] Among resin-based dental composites, specifically the Wetting resin, resin monomers containing diurethane dimethacrylate (UDMA) have a high molecular weight, which increases the viscosity of this material. Moreover, the Wetting resin contains triethylene glycol dimethacrylate (TEGDMA) in the same proportion as UDMA. TEGDMA is more sensitive to changes in pH and solvent composition; therefore, it may potentially absorb and react with pigments.[34] Our findings suggest that the changes in color and roughness were more affected by the viscosity of the modeling materials than by the presence of solvents in their composition. Despite the presence of an acidic functional monomer, using a Universal adhesive as a modeling liquid, there were smaller changes in color and roughness, which were similar to those observed in the use of the Scotchbond. A previous study has also reported the reliability of the Universal adhesive use for this purpose.[6] In addition, Scotchbond as modeling liquid has already been shown not to affect the cohesive strength of the resin composite.[18] 2,2-bis-[4-(2-hydroxy-3-methacryloyloxypropoxy)phenyl]-propane) (bis-GMA) and hydroxyethylmethacrylate (HEMA), without the combination of solvents, form molecules with high molecular weight and, consequently, a better bond at the interfaces.[18] It is known, however, that the presence of solvents can compromise some mechanical properties, which were not evaluated in the present study.

In general, we found a higher degree of staining in the control group after immersion. Moreover, toothbrushing was not effective in reducing this color change. This can be problematic in patients with resin composite restorations in the esthetic zone. Other studies on these color changes have immersed test specimens in various solutions.[7,12,15] In the present study, the specimens were continuously immersed in red wine for 24 h; thus, it was possible to combine the effects of staining, erosion, and degradation, as wine is acidic. Acidic beverages commonly consumed by people negatively influence the physical and mechanical properties of composites.[5]

Most studies have attributed the changes in specimen color to the effects of experimental staining challenges, without considering the influence of toothbrushing. Therefore, another important observation from the present study was that the toothbrushing procedures allowed the inclusion of

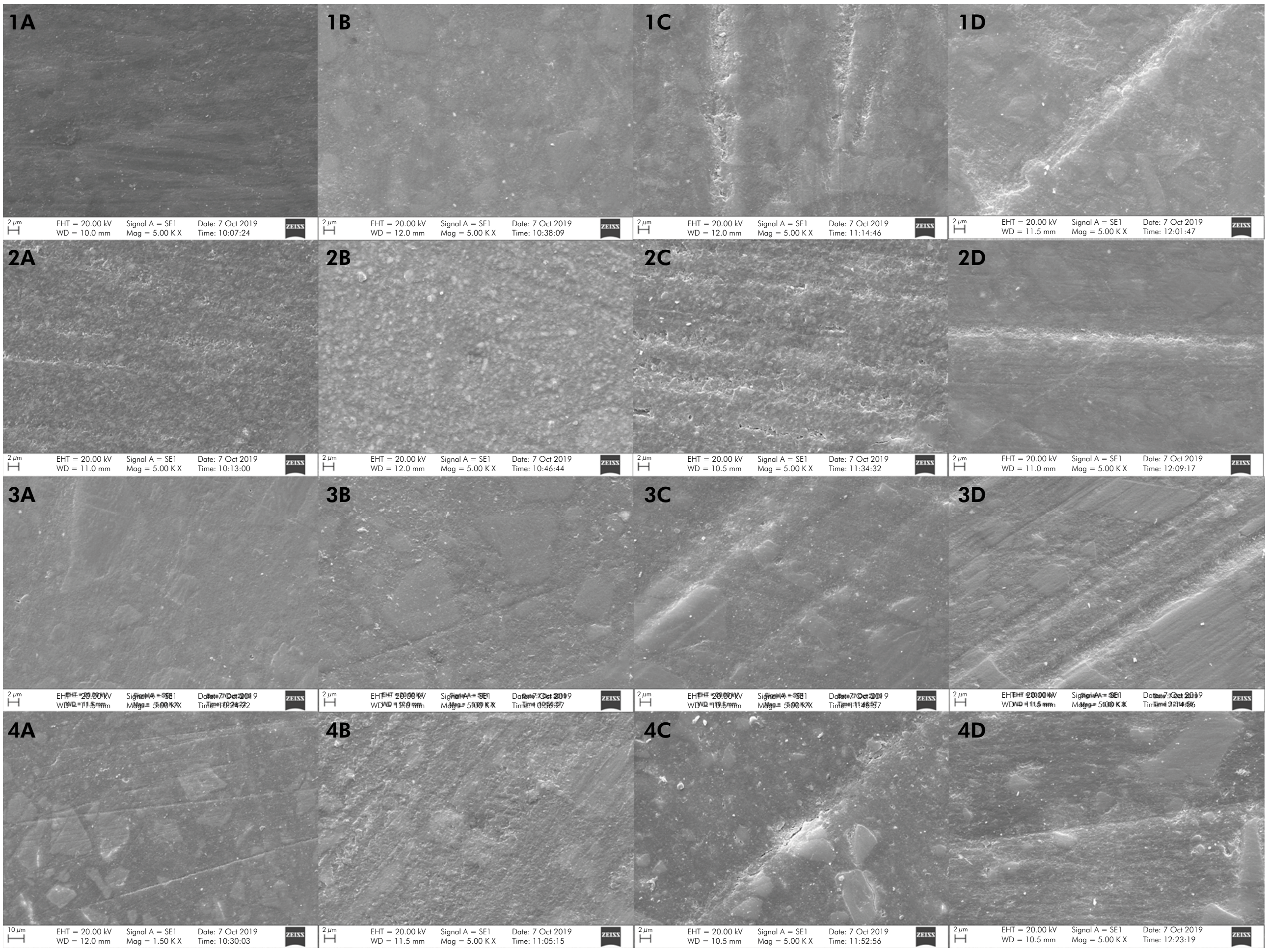

Figure 3. Scanning electron microscopy representative images of resin composite surfaces after being modeled with coatings at 5000x. Line 1: Control group; Line 2: Wetting resin; Line 3: Scotchbond adhesive; Line 4: Universal adhesive. The letters corresponded to baseline (a), after staining - (T1) (b), after 5,000 cycles - (T2) (c) and after 10,000 toothbrushing cycles - (T4) (d).

another condition of the oral environment; namely, the abrasive challenge. Simulated toothbrushing reduced the color changes caused by immersion in red wine but did not increase WI. All values of ΔE_{00} in this study exceeded the acceptability threshold (ΔE_{00} = 1.77). This threshold was defined as the color difference between two objects, which required acceptance by 50% of observers to consider it clinically acceptable.[29] The surface stains caused by the staining protocol used in the present study were removable; and they were removed using a toothbrush and regular dentifrice, consistent with the findings of other studies.[12,15] Nevertheless, red wine had the highest staining potential.[5] The final mean values of all the groups were considerably above the confidence interval (CI: 1.23–2.37).[29] Thus, in the present study, wine caused an irreversible stain that could not be completely removed to increase the WI. The dentifrice used in the present study had a relative dentin abrasion index of 70 (the scale ranges from 0 to 250), which is considered moderately abrasive. This dentifrice was chosen because it is commonly used and available to patients; however, it did not have sufficient abrasive potential to remove the surface staining caused by wine.[13,14]

As the composite surfaces were polished, the differences in smoothness among the treatments could be related to changes in the composite properties caused by the modeling liquid. The Wetting resin showed higher surface roughness and color change values compared to those in the other treatments. The higher viscosity level of this resin may have contributed to this finding because it produced irregular surface thickness owing to air bubbles trapped within the coating layer.[21] The numerous porosities present on the surface after the Wetting resin application with a brush, as well as the large voids resulting from the abrasion of the organic matrix and removal of inorganic fillers from the surface during polishing and toothbrushing, may also have contributed to these findings. These surface porosities caused losses of mass and water sorption, which may have promoted higher roughness and color change.[25] However, none of the modeling liquids used in the present study reduced the roughness measured at baseline compared to the control. Thus, the findings suggest the need to polish restorations even when a modeling liquid is used.

The possible explanations for the reduction in surface roughness and susceptibility to staining between the two types of adhesives tested include the following: low viscosity, which reduced the presence of defects in the bulk of the composite, and the relative hydrophobic composition, which may have protected the composite from hydrolysis and further deleterious effects.[25] Despite the presence of hydrophilic monomers and solvents, the Universal adhesive showed higher color stability in the present study. The predominance of 60–70% of BISGMA monomer resulted in higher viscosity in the Scotchbond adhesive, when compared to the Universal adhesive, which contained only 15–25% of BISGMA. Another explanation for the better outcomes of the Universal adhesive could be the higher b* values of the Universal adhesive, which were probably directly related to the greater amount of amine in the material.[35]

A limitation of the present study was that the specimens were immersed in red wine for a long period that did not reproduce the clinical environment. Therefore, the color changes observed in this study were likely overestimated. Moreover, the data observed for the materials evaluated in the present study cannot be extrapolated to other materials because differences in composition could affect the outcomes. Besides the afore-mentioned effect of the resin monomer composition, the inorganic content of the modeling liquids used in this study may also have affected the properties of the materials.[17] Nonetheless, the lack of complete information about these commercial formulations made it difficult to evaluate these differences. Lastly, the two adhesives evaluated were commonly available at dental offices and the clinician was not required to have a material specifically designed for use as a modeling liquid. Thus, studies that evaluate different materials and staining liquids and the amount of modeling liquid used may contribute to a better understanding of the clinical reality. Considering that modeling liquids are applied directly on the last layer of the resin composite during restoration, modeling with adhesives is an alternative[20,25,30] to reduce color change and surface roughness, consequently improving the surface quality of a resin composite.

Conclusions

Based on the findings of this study, it can be concluded that the Wetting resin showed the highest surface roughness and staining potentials. Toothbrushing reduced the color changes (ΔE_{00}) produced by wine staining, except for the Wetting resin. Both adhesives were beneficial as a modeling liquid, promoting lower surface roughness, better color stability, higher WI, and lower opacity values.

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