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Influence of nonhazardous postprocessing solutions and surface treatments on the surface roughness and color stability of resins used for additively manufactured definitive restorations

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ABSTRACT

Statement of problem. Knowledge of the surface roughness and color stability of definitively intended additively manufactured (AM) resins when different postprocessing cleaning solutions and surface treatments are applied is limited.

Purpose. The purpose of this in vitro study was to evaluate the effect of postprocessing cleaning solution and surface treatment (polishing and coffee thermocycling) on the surface roughness and color stability of resins intended for AM definitive restorations. In addition, the color coordinates were compared with an A1 shade tab.

Material and methods. Sixty specimens were AM from 2 different resins, a glass-filler reinforced composite resin (AM-CR) and urethane acrylate-based resin (AM-UA), for definitive restorations. The specimens were divided into 3 groups based on the postprocessing cleaning solution (n=10): 96% ethanol, water-based solvent, and methyl ether solvent. The surface roughness (Ra) and color coordinates were measured before polishing, after polishing, and after coffee thermocycling for 5000 cycles. Color difference values (ΔE_{00}) were calculated, and color coordinates were compared with a reference shade tab (α=.05).

Results. AM-CR had a lower R_a with ethanol than methyl ether solvent before polishing (P=.006). AM-UA had the lowest R_a with ethanol and the highest R_a with water-based solvent before polishing ($P\leq$.001). Irrespective of material and postprocessing solution, R_a decreased after polishing ($P\leq$.001). AM-CR had the highest ΔE_{00} with methyl ether solvent after polishing and after coffee thermocycling ($P\leq$.002). AM-CR had the lowest ΔE_{00} with ethanol after coffee thermocycling ($P\leq$.003).

Conclusions. Resin type, postprocessing cleaning solution, and surface treatment affected the surface roughness and color stability of AM resins intended for definitive restorations. (J Prosthet Dent 2025;134:167-175)

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Clinical Implications

To reduce hazardous effects during postprocessing, definitive restorations made of AM-CR resin can be cleaned with the water-based solvent, and definitive restorations made of AM-UA resin can be cleaned with the water-based solvent or methyl ether solvent.

Computer-aided design and computer-aided manufacturing (CAD-CAM) techniques, including additive (AM) or subtractive (SM) manufacturing technologies, are increasingly being used in restorative dentistry.[1] AM or 3-dimensional (3D) printing has advantages, including cost effectiveness and reduced waste, noise, and heat emission, since burs are not required; this enables complicated geometry fabrication and the elimination of microsize cracks which may occur with SM.[2] AM has been increasingly used with the urethane acrylate-based, glass-filler reinforced, or dual-network composite resins indicated for fixed definitive restorations.[3–6]

AM of photopolymerizable resin requires postprocessing to remove unpolymerized resin, typically using isopropyl alcohol (IPA) or ethanol.[7,8] However, inhaling IPA or ethanol can be hazardous and may cause pollution.[9] Furthermore, IPA and ethanol are flammable and highly volatile, requiring safety precautions.[10,11] Recently, as an alternative ecologically friendly AM, alcohol-free postprocessing cleaning solutions such as methyl ether or water-based solvents have been introduced.[12,13] These solutions are odorless, nonflammable, and biodegradable, have nontoxic waste products with lower hazardous air pollutants, and are safer and easier to use.[12,13]

Unpolymerized resin remnants may affect the surface texture, characteristics, and color stability of a restoration.[14] Therefore, surface cleaning is essential for the clinical stability of AM definitive restorations, as low surface roughness can reduce bacterial adhesion[15,16] and color change for long-term success.[17] In addition, the material must resist temperature changes caused by food and beverages such as coffee.[17] The authors are unaware of a study that has evaluated the surface roughness and color stability of resins intended for AM definitive restorations and cleaned with alcohol-free water or methyl ether solvent-based postprocessing cleaning solutions. The present study aimed to evaluate the effect of a postprocessing cleaning solution and surface treatment (polishing and coffee thermocycling) on the surface roughness and color stability of resins intended for AM definitive restorations. In addition, the color coordinates of these resins were compared with the A1 shade tab to observe their behavior in relation to the target shade. The null hypotheses were that the postprocessing cleaning solution would not affect the surface roughness (Ra) and the color change (ΔE_{00}) of different resins after different surface treatments; that the resin type would not affect the Ra and ΔE_{00} when applying the same postprocessing cleaning solution; and that no difference would be detected in the color coordinates of resin-cleaning solution pairs measured in different surface treatment states and against the reference shade tab.

MATERIAL AND METHODS

A total of 60 disk-shaped specimens (∅10×1.5 mm)[18] were AM from a glass-filler reinforced composite resin (AM-CR, Crowntec, A1 color; Saremco Dental AG) and a urethane acrylate-based resin (AM-UA, TC-80DP, A1 color; Graphy) (n=30) marketed for definitive restorations. The specimens were fabricated by using a digital light processing (DLP) printer (MAX UV; Asiga) with a 45-degree build angle and 50-µm layer thickness. After printing, the specimens were divided into 3 groups based on the postprocessing cleaning solution (n=10). The first was the 96% ethanol (Ethanol absolut; Dr. Grogg Chemie AG): AM-UA specimens were cleaned in an ultrasonic bath for 45 seconds and further washed with an ethanol-soaked cloth, while AM-CR specimens were cleaned with an ethanol-soaked cloth followed by careful removal of unpolymerized residual resin with a cotton swab. The second group was the water-based solvent (Saremco Dental AG): the solvent was prepared with a mixing ratio of 4 (deionized water): 1 (concentrate), and then the specimens were ultrasonically cleaned for 3 minutes in this solution, followed by a warm water rinse and air drying. A freshly prepared solution was used for each material. The third group was the methyl ether solvent (Weiton-3D Resin Cleaner; Johannes Weithas): The specimens were ultrasonically cleaned for 2 minutes in this solution, followed by another 3 minutes of ultrasonic cleaning in fresh solution. All specimens were then air dried and postpolymerized by using a xenon lamp-polymerization unit (Otoflash G171; NK Optik) (2×2000 lighting exposures with nitrogen gas atmosphere). Ten specimens per resin-postprocessing cleaning solution group were determined based on an a priori power analysis (95% statistical power, 95% confidence interval, and effect size of 0.759).[14,17] The surface roughness (Ra) and color coordinates of the specimens were measured at 3 different surface treatments: before polishing (baseline), after polishing, and after coffee thermocycling.

Surface roughness (R_a, µm) was measured with a profilometer with a CWL 300-µm sensor (FRT MicroProf 100; Fries Research Technology GmbH).[19] Six linear traces were recorded for each specimen: 3 horizontal and 3 vertical with 1-mm distance using a 5.5-mm trace length, 0.8-mm cut-off (Lc) wavelength, 5501 point/line pixel density, and 3-nm resolution in the z-dimension.[19] The average Ra values per specimen were calculated.

The color coordinates (L*, a*, and b*) of specimens were measured 3 times on a gray background using a digital spectrophotometer (CM-26d; Konica Minolta) with Commission International de I'Eclairage (CIE) D65 illumination and 2-degree human observer characteristics. For the optical contact between AM specimens and the gray background, a saturated sucrose solution (~1.5 refractive index) was used.[17,20] The spectrophotometer was calibrated before measuring each group. The average of 3 measurements on a specimen was calculated. The color measurements were conducted by a single operator (N.M.R.) in a temperature- and humidity-regulated room (20 °C and 45%) under natural daylight.[21] The color coordinates of the shade tab (Vita A1 shade tab; Vita Zahnfabrik) were also measured as reference values.

After baseline surface roughness and color measurements, the specimens were polished using a 2-step polishing kit (Diatech Lab Finishing and Polishing Kit; Coltène) (7000 rpm for 90 seconds with each polishing bur) and a polishing paste (Zircon Brite; Klasse 4 Dental GmbH).[20] Then, the surface roughness and color measurements were repeated after polishing as described above. Subsequently, the polished specimens were subjected to coffee thermocycling for 5000 cycles (SD Mechatronik Thermocycler; SD Mechatronik GmbH) (5 to 55 °C, 10 seconds transfer, 30 seconds dwell time). The coffee solution was prepared by adding a tablespoon of coffee (Intenso Roasted and Grounded; Kaffeehof GmbH) into 177 mL of water.[17,20] The coffee in the hot and cold tanks was replaced with freshly made coffee every 12 hours. After coffee thermocycling, the specimen surfaces were cleaned of coffee extracts and brushed 10 times using toothpaste (Nevadent Complex 3; DENTAL-Kosmetik GmbH).[17,20] Then, the specimens were ultrasonically cleaned for 10 minutes and dried. Surface roughness and color measurements were repeated as described previously. The color difference values (ΔE_{00}) of each specimen using the color coordinates measured at different surface treatments (before and after polishing, after polishing, and after coffee thermocycling) were calculated using the CIEDE2000 formula. The parametric factors (KL, KC, and KH) were set to 1.[17,20] The color coordinates (L*, a*, and b*) of each specimen were compared with those of the shade tab (Vita A1 shade tab; Vita Zahnfabrik). The schematic diagram and the specimens are presented in Figures 1 and 2.

Data normality was evaluated by using the Kolmogorov-Smirnov tests, which indicated normal distribution for surface roughness and ΔE_{00}. Surface roughness and ΔE_{00} were assessed by using a generalized linear mixed effect model and post hoc Tukey HSD test with material, postprocessing cleaning solutions, different surface treatments, and the interaction between these factors. Using the CIEDE2000 50% perceptibility (0.8 ΔE^*_{00}) and acceptability (1.8 ΔE^*_{00}) thresholds,[22] CIEDE2000 (ΔE_{00}) values were evaluated. Color coordinates (L*, a*, and b*) of the shade tab and materials under different postprocessing cleaning solutions were analyzed using the Wilcoxon test. All analyses were performed by using a statistical analysis software program (IBM SPSS Statistics, v23; IBM Corp) (α=.05).

RESULTS

For the surface roughness (R_a), according to the 3-way ANOVA, a significant interaction was observed among the resin type, postprocessing cleaning solution, and surface treatment (df=4, adj MS=0.3963, F=7.55, P<.001). The effect of the postprocessing solution on the R_a of the tested resins varied depending on the resin within surface treatments (P≤.001) (Table 1); AM-CR had a lower R_a with ethanol than methyl ether solvent before polishing (P=.006). AM-UA had the lowest R_a with ethanol, whereas it had the highest R_a with water-based solvent before polishing (P≤.001). The effect of postprocessing solution on the surface roughness was similar for after polishing and after coffee thermocycling conditions for each resin (P≥.99).

Resin type did not significantly affect the Ra when the same postprocessing cleaning solution was used (P≥.05), except for before polishing R_a values with the water-based solvent; AM-CR had a lower R_a than AM-UA (P≤.001). Irrespective of resin type and postprocessing solution, R_a decreased more significantly after polishing than before polishing (P≤.001). The effect of coffee thermocycling on the surface roughness was not statistically significant for each resin (P=.952). For color difference (ΔE_{00}), according to the 3-way ANOVA, a significant interaction was observed among resin type, postprocessing cleaning solutions, and different surface treatments (df=4, adj MS=2.924, F=12.54, P<.001).

The effect of postprocessing solution on model resin ΔE_{00} values varied depending on the resin type and surface treatment (Table 2, Fig. 3); AM-CR had the highest ΔE_{00} values when methyl ether solvent was used after polishing and after coffee thermocycling (P≤.002). AM-CR had the lowest ΔE_{00} values with ethanol after coffee thermocycling (P≤.003). AM-UA had similar ΔE_{00} values among different postprocessing solutions after polishing and after coffee thermocycling (P≥.05).

Resin type significantly affected the values of color ΔE_{00} when the same postprocessing cleaning solution

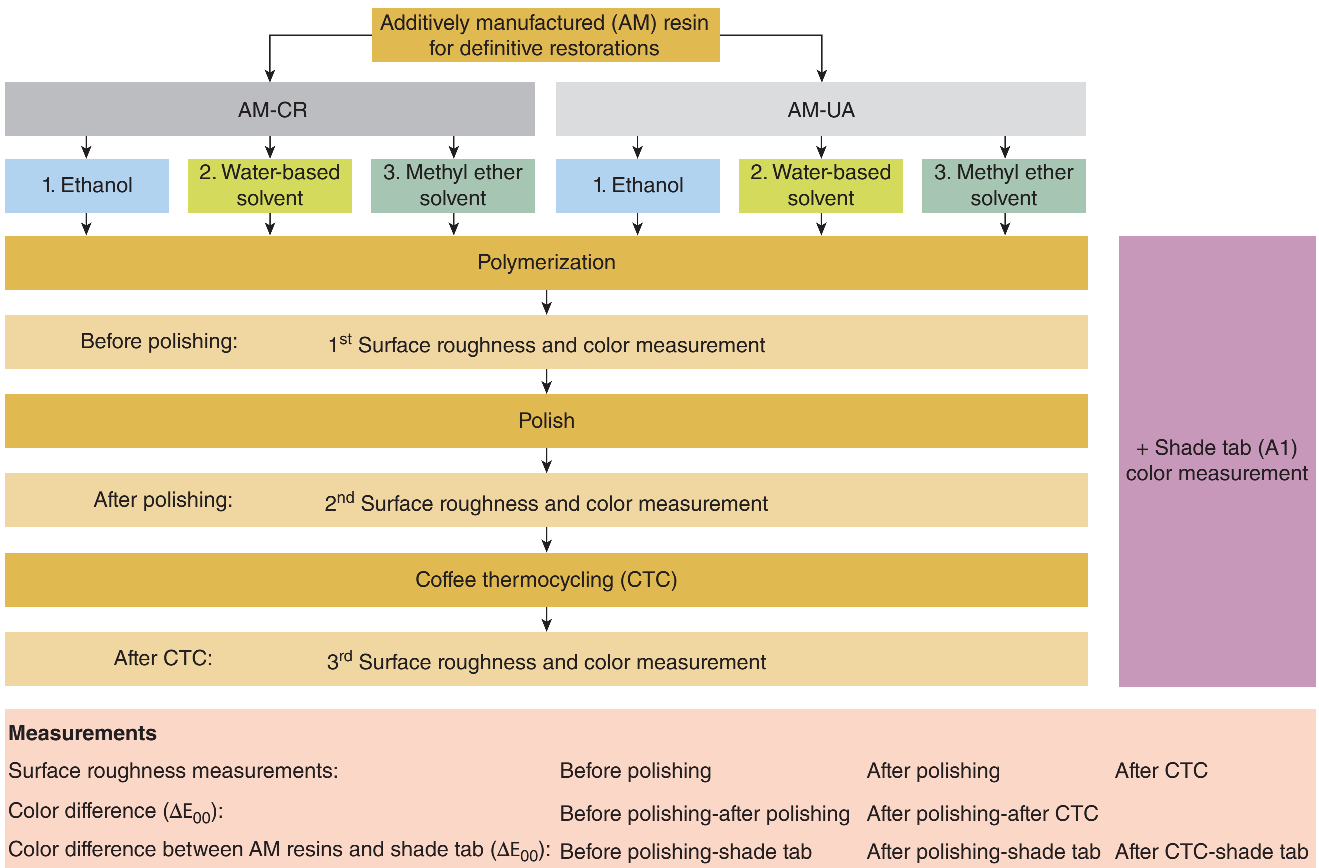

Figure 1. Schematic diagram of study.

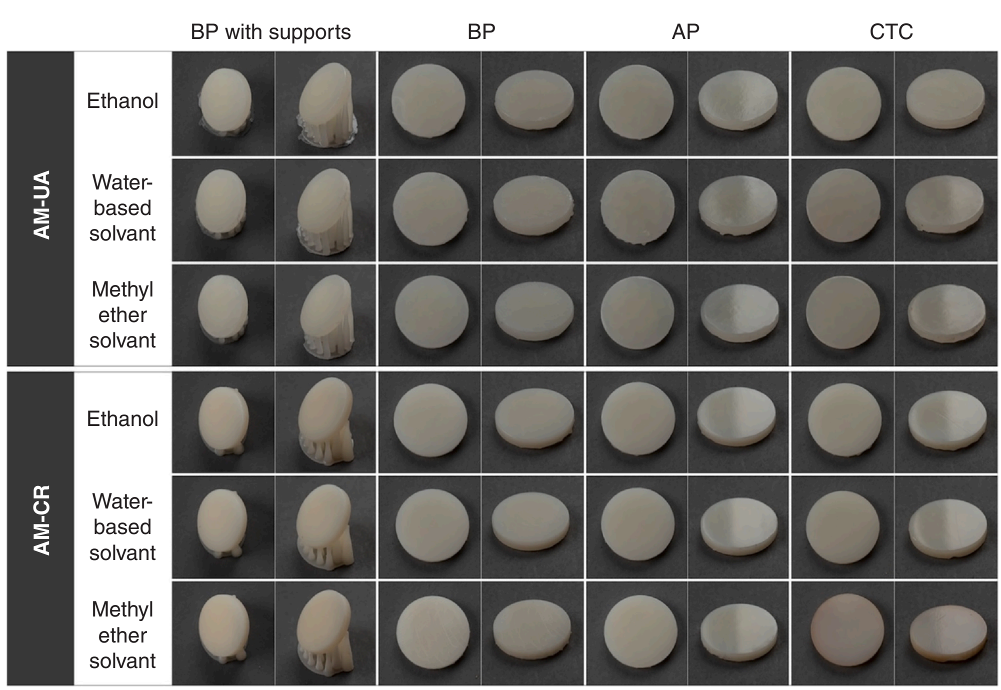

Figure 2. Each resin-postprocessing cleaning solution pairs at different surface treatment. AM-UA, urethane acrylate-based resin (TC-80DP), AM-CR, glass-filler reinforced composite resin (Crowntec). BP, before polishing; AP, after polishing; and CTC, coffee thermocycling.

Table 1. Descriptive statistics of R_a (μm) values measured at three different surface treatments for each resin-postprocessing cleaning solution pair

Surface Treatment	Solution	AM-CR	AM-UA	Total
		Mean ±SD	Mean ±SD	Mean ±SD
Before polishing	Ethanol	1.84 ±0.32^{d}	2.01 ±0.24^{cd}	1.9 ±0.3^{B}
	Water-based solvent	1.91 ±0.41^{cd}	2.95 ±0.55^{a}	2.4 ±0.7^{A}
	Methyl ether solvent	2.26 ±0.46^{bc}	2.41 ±0.17^{b}	2.3 ±0.3^{A}
After polishing	Ethanol	0.2 ±0.13^{e}	0.17 ±0.04^{e}	0.2 ±0.1^{C}
	Water-based solvent	0.12 ±0.03^{e}	0.17 ±0.07^{e}	0.1 ±0.1^{C}
	Methyl ether solvent	0.13 ±0.05^{e}	0.16 ±0.06^{e}	0.1 ±0.1^{C}
After coffee thermocycling	Ethanol	0.24 ±0.17^{e}	0.15 ±0.02^{e}	0.2 ±0.1^{C}
	Water-based solvent	0.12 ±0.01^{e}	0.18 ±0.07^{e}	0.2 ±0.1^{C}
	Methyl ether solvent	0.12 ±0.02^{e}	0.2 ±0.07^{e}	0.2 ±0.1^{C}

Additively manufactured (AM) resins for definitive use: AM-CR, glass-filler reinforced composite resin (Crowntec); AM-UA, urethane acrylate-based resin (Tera Harz TC-80DP). R_a, surface roughness; SD, standard deviation. Different lowercase letters indicate differences among each resin-post-processing cleaning solution pair and different uppercase letters indicate differences among total value of tested resins with different post-processing cleaning solutions (*P*<.05).

Table 2. Descriptive statistics of ΔE_{00} values calculated between color coordinate values measured at three different surface treatments for each resin-postprocessing cleaning solution pair

	Solution	AM-CR	AM-UA	Total
		Mean ±SD	Mean ±SD	Mean ±SD
ΔE_{00} (between before polishing and after polishing)	Ethanol	2.38 ±0.4^{gh}	3.97 ±0.31^{cde}	3,2 ±0,9^{C}
	Water-based solvent	2.25 ±0.17^{h}	4.12 ±0.51^{cd}	3,2 ±1^{C}
	Methyl ether solvent	4.95 ±1.02^{b}	3.96 ±0.3^{cde}	4,5 ±0,9^{A}
ΔE_{00} (between after polishing and after coffee thermocycling)	Ethanol	1.27 ±0.28^{i}	2.96 ±0.21^{fgh}	2,1 ±0,9^{D}
	Water-based solvent	2.21 ±0.15^{h}	2.82 ±0.56^{fgh}	2,5 ±0,5^{D}
	Methyl ether solvent	3.44 ±0.62^{def}	2.86 ±0.26^{fgh}	3,2 ±0,6^{C}

Additively manufactured (AM) resins for definitive use: AM-CR, glass-filler reinforced composite resin (Crowntec); AM-UA, an urethane acrylate-based resin (Tera Harz TC-80DP). ΔE_{00}, Color difference values; SD, standard deviation. Different lowercase letters indicate differences among each resin-post-processing cleaning solution pair and different uppercase letters indicate differences among total value of tested resins with different postprocessing cleaning solutions (*P*<.05).

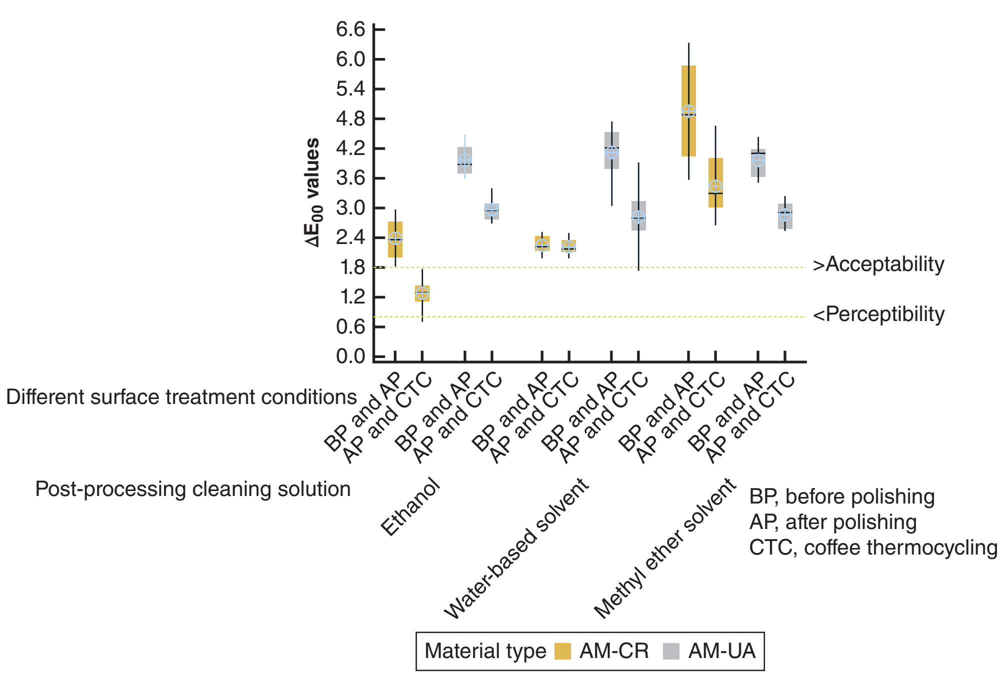

Figure 3. Box-plot graph (mean values and 95% confidence intervals) of ΔE_{00} values of each resin-postprocessing cleaning solution pair calculated using color coordinates measured at three different surface treatments (BP, before polishing; AP, after polishing; and CTC, coffee thermocycling). AM-UA, urethane acrylate-based resin (TC-80DP), AM-CR, glass-filler reinforced composite resin (Crowntec).

was used ($P\leq.001$). After polishing, AM-CR had lower ΔE_{00} values than AM-UA when ethanol or water-based solvent was used ($P\leq.001$), whereas AM-CR had a higher ΔE_{00} values than AM-UA when methyl ether solvent was used ($P\leq.001$). After coffee thermocycling, AM-CR had lower ΔE_{00} values than AM-UA when ethanol was used ($P\leq.001$).

Irrespective of the postprocessing solution, AM-CR specimens had higher L* and lower a* and b* values than those of the shade tab before polishing ($P\leq.017$), except for the L* values of water-based solvent (P=.203). AM-UA had lower L*, a*, and b* values than those of the shade tab with all cleaning solutions (P=.005) before polishing. Regardless of cleaning solutions, AM-CR and AM-UA had lower L*, a*, and b* values than those of the shade tab after both polishing and coffee thermocycling (P=.005) (Fig. 4).

DISCUSSION

Surface cleaning is essential for the clinical stability of additively manufactured definitive restorations. Previous studies[17,20,23] have reported the effect of coffee thermocycling on the color stability and translucency, surface roughness, and microhardness of AM resins for definitive restorations using only alcohol postprocessing. To the authors' knowledge, only 1 study has evaluated the effect of cleaning solution and its duration on the mechanical properties of AM resin used for interim prostheses,[24] and another has assessed the fabrication accuracy of an AM dental cast resin.[10] A previous study investigated the effect of cleaning solution on the fracture load and 2-body wear of AM fixed dental prostheses (FDPs) for long-term interim restoration use,[25] and another evaluated the effect of cleaning solution on the degree of conversion, surface roughness, and flexural strength of FDPs again for long-term interim restoration use.[14] The present study aimed to evaluate the effect of postprocessing cleaning solution and surface treatment on the surface roughness and color stability of resins intended for AM definitive restorations and to compare the color coordinates of these resins with those of the shade tab (A1).

Significant differences were found in surface roughness and color stability between different postprocessing solutions and within each resin and between AM resins with the same postprocessing solutions under different surface treatments. Significant differences were found in the color coordinates of resin-cleaning solution pairs and the shade tab under different surface treatments. Therefore, the null hypotheses that the postprocessing cleaning solution would not affect the surface roughness (Ra) and the color change (ΔE_{00}) of different resins after different surface treatments; that the resin type would not affect Ra and ΔE_{00} when applying the same postprocessing cleaning solution; and that no difference would be detected in the color coordinates of resin-cleaning solution pairs measured at different surface treatment states and the reference shade tab were rejected.

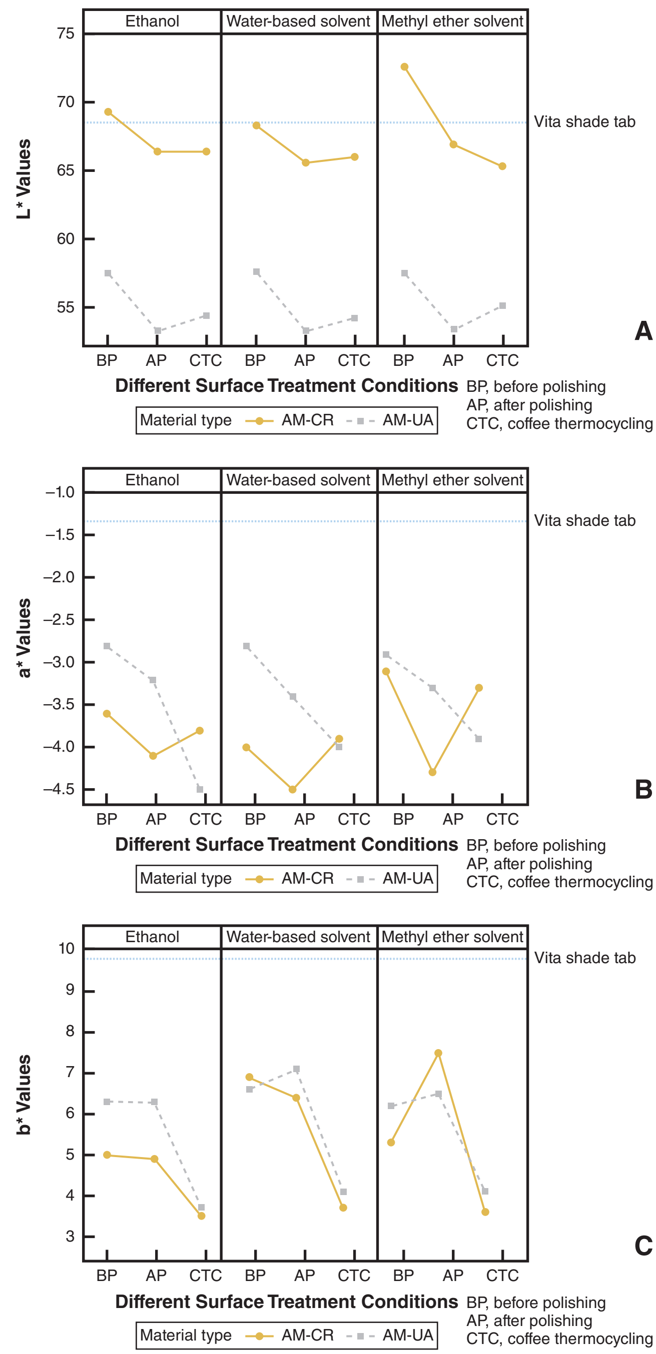

Figure 4. Mean values of tested resins cleaned with different postprocessing cleaning solutions at each surface treatment, connected with lines displaying change. A, L*. B. a*. C, b*. BP, before polishing; AP, after polishing; and CTC, coffee thermocycling. AM-UA, urethane acrylate-based resin (TC-80DP), AM-CR, glass-filler reinforced composite resin (Crowntec).

For AM-CR, methyl ether solvent resulted in higher R_a values than ethanol before polishing. For AM-UA, the R_a values were the highest with the water-based solvent and the lowest with ethanol before polishing. The difference among postprocessing solutions before polishing in both resins may be considered negligible, as all postprocessing solutions resulted in clinically unacceptable R_a values (>0.2 μm).[26] Similarly, Mayer et al[14] and Hwangbo et al[7] reported different surface roughness results with varying solutions of postprocessing for 3D printed resins intended for interim restorations and for 3D printed resin for definitive prostheses, respectively.

After polishing, the R_a values of the AM specimens fell close to or below the acceptability threshold and did not significantly change after coffee thermocycling. Tested AM resins demonstrated durability against long-term coffee consumption given that 5000 thermocycles simulate 6 months of intraoral use and that coffee is consumed intermittently rather than constantly as an intraoral fluid.[27,28] After polishing and after coffee thermocycling, AM-CR and AM-UA had similar R_a values with different postprocessing solutions. Previous studies were consistent with these findings that polishing reduces the surface roughness of AM resins for definitive restorations[29] and that the R_a of polymer-based materials did not increase above the clinically acceptable threshold after coffee thermocycling.[30,31] A negative correlation between the surface roughness and the degree of conversion has been reported,[14] which may result from unpolymerized residue on the surface presenting as surface roughness after cleaning.[14] However, with polishing, it appears that these unpolymerized residues are removed from the surface, which might provide durable surfaces. Recent studies have investigated the effect of postprocessing cleaning time on the surface roughness of AM resins[7,32]; however, in these studies, the specimens were not polished after cleaning. In the present study, the manufacturers' recommended cleaning time was applied. Therefore, a direct comparison of these study results with those of the present study is difficult.

The authors are unaware of previous studies that evaluated the effect of postprocessing solutions on the color change of AM definitive resin restorations. Therefore, directly comparing the results of the present study with those of previous studies is difficult. AM-CR had the highest color change after polishing and after coffee thermocycling with a methyl ether solvent. However, postprocessing solutions resulted in similar color change in AM-UA within after polishing and after coffee thermocycling. The color change after coffee thermocycling was lower than the color change after polishing for both resins, except for AM-CR with water-based solvent. The polished surfaces might be more resistant to color change.[33] The color of polishing paste may affect the color of AM resins, which should be further evaluated. After polishing, AM-CR had less color change than AM-UA with ethanol and water-based solvent, whereas it had more color change than AM-UA with methyl ether solvent. After coffee thermocycling, AM-CR had less color change than AM-UA with ethanol. AM-UA is urethane acrylate-based resin, while AM-CR is glass-filler reinforced composite resin. Yilmaz et al[17] evaluated the effect of resin thickness and coffee thermocycling on the color change and translucency of the AM definitive restorations made of the same resins tested in the present study. Their study[17] used ethanol for postprocessing and reported comparable results for the same AM resins, indicating that AM-UA had more color change than AM-CR with ethanol postprocessing. The authors[17] attributed the difference in color change to differences in chemical composition, including the particle size and distribution, the polarity of monomers, the amount of crosslinking, the initiator system, and the pigment stability. Varied effects of different postprocessing solutions on the color change of tested AM resins may be associated with the difference in absorption of the postprocessing solution because the chemical composition of the resin and the proportion of each monomer in the resin determine its water absorption capacity.[34] After polishing and after coffee thermocycling, all color change values were above the perceptibility and acceptability thresholds in both AM resins, except for AM-CR-ethanol after coffee thermocycling. After coffee thermocycling, AM-CR-ethanol had a color change below the acceptability but above the perceptibility threshold. The unacceptable color change of tested resins may be attributed to the nature of the AM method, in which an object is built layer-by-layer and consecutive layers are polymerized one at a time.[35] Yilmaz et al[17] reported that residual monomers and microporosities caused by incomplete polymerization during consecutive layering in AM might be the reason for higher ΔE_{00} values. Therefore, the tested resins can be recommended for posterior restorations, where color change may not be as crucial. The L* component indicates brightness.[36] All L* values decreased after polishing and coffee thermocycling compared with before polishing, regardless of the resin or the cleaning solution. Compared with the shade tab, before polishing, ethanol and methyl ether solvent postprocessing solutions produced a brighter shade with AM-CR, indicated by the higher L* values. However, after polishing and coffee thermocycling, the L* values of AM-CR decreased below that of the shade tabs. AM-CR had higher L* values than AM-UA with all postprocessing solutions in all surface treatments, indicating that AM-CR had a brighter shade than AM-UA. AM-CR and AM-UA had a* and b* values lower than those of the shade tab with all postprocessing solutions in all surface treatments. The a* values for AM-CR were reduced after polishing and increased after coffee thermocycling, indicating increased red content.[36] For AM-UA, the a* values gradually decreased after polishing and after coffee thermocycling, indicating increased green content.[36] Methyl ether solvent increased the b* value with AM-CR after polishing, making it more yellow.[36] However, after coffee thermocycling, the b* values of AM-CR decreased regardless of the cleaning solution, increasing the blue content.[36] For AM-UA, only the water-based rinse increased the b* value slightly after polishing. After coffee thermocycling, all b* values decreased. A previous study compared the color dimensions of AM resins for interim restorations with conventional interim restorative materials and found that AM resins failed to match the color of conventional resins. A custom shade guide for AM resin was recommended.[36] The color of tested resins in this study was significantly different than the shade tab, which supports this recommendation.

Using AM resin for definitive restorations with water-based solvent or methyl ether solvent postprocessing could enable ecologically friendly and sustainable restoration fabrication and addresses the drawbacks of the hazardous impacts of alcohol postprocessing. Furthermore, the manufacturer claims that the water-based solvent and the methyl ether solvent can be reused,[12,13] which may contribute to recycling and less waste. The use of resins for AM definitive restorations chairside can eliminate the odor of alcohol and reduce clinician, dental laboratory technician, and patient exposure in clinical practice or dental laboratories. In terms of surface roughness and color change results, either ethanol or water-based solvent postprocessing cleaning solutions would be more suitable when the tested AM-CR resin is used. Ethanol, methyl ether solvent, or water-based solvent postprocessing cleaning solutions would be suitable when tested AM-UA resin is used.

Limitations of this study included that the in vitro design may not precisely replicate the clinical situation, and the results may vary with wine, juices, curry, and distilled water.[37,38] Tooth brushing can also influence the surface characteristics of resins and increase roughness[19,26]; its effects should be investigated in future studies. Although the resins tested varied in composition, resins in different compositions available in the market may have different outcomes. In addition, 3 cleaning solutions were used, and other solutions at different concentrations and cleaning times may affect the results. Further research that includes additional materials is needed to better understand the impact of the postprocessing step on the structural and mechanical properties, residual monomer release, and manufacturing accuracy and fit of AM resins.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The interaction between the resin, postprocessing cleaning solution, and surface treatment had a significant effect on the surface roughness and color stability of the tested resins.
2. Before polishing, tested resins had surface roughness above the clinically acceptable threshold (>0.2 μm), decreasing toward or below the acceptability threshold after polishing.
3. The tested resins had similar surface roughness with the same postprocessing cleaning solution after polishing, except when the water-based solvent was used before polishing.
4. All color changes were above the perceptibility and acceptability thresholds in both additively manufactured resins after polishing and coffee thermocycling, except for AM-CR cleaned with ethanol after coffee thermocycling, which exceeded only the perceptibility threshold.
5. All resin color coordinates were below those of the shade tab before and after polishing and after coffee thermocycling, regardless of the postprocessing solution, except for the L* value of AM-CR before polishing.
6. For fewer hazardous effects, water-based solvent can be used for AM-CR and AM-UA resins, and methyl ether solvent can be used for AM-UA resin to clean their surfaces without compromising surface roughness or color stability.

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