Influence of Surface Coatings on Color Stability and Surface Roughness of Provisional Prosthodontic Material

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Abstract

Discoloration can be the problem of provisional restorations, especially in long-term treatment cases. The surface coating materials may influence the properties of provisional restorative material.

This study aimed to evaluate the effect of silane-SiO2 film coating on the color stability and surface roughness of provisional fixed prosthodontic material compared to three commercial surface coating agents.

A total of 160 specimens were fabricated from auto-polymerized polymethyl methacrylate resin (PMMA: Unifast Trad) and divided randomly into five groups according to applied surface coating procedures: non-coated (control) and four surface coated (silane-SiO2, Palaseal, Biscover LV, Optiglaze). Surface roughness (Ra) values were assessed by a profilometer. One specimen for each group, surface morphology was analyzed by SEM examination and element composition was analyzed by energy dispersive spectroscopy (EDS) before and after immersion in distilled water for 30 days. Color changes (ΔE) were measured as CIE L*a*b* value with a spectrophotometer before immersion and 1 day, 7 days, and 30 days after immersion in solutions (distilled water, tea, coffee). The data were statistically analyzed using repeated measure ANOVA on the color stability test and one-way ANOVA on the surface roughness with Bonferroni adjustment for multiple comparisons (α=.05).

The mean Ra value of all groups ranged from 0.201 to 0.264. No significant differences were found among groups on surface roughness result(P>.05). Silane-SiO2 coated PMMA acrylic resin presented the lowest ΔE value in all conditions. Palaseal group showed the highest color change in the coffee solution and Biscover LV coated showed the highest color alteration in distilled water and tea solution. The different surface coatings showed significant color changes in acrylic resin (P<.05).

Silane-SiO2 film-coated acrylic resin showed the most color stability compared to commercial surface coating agents and conventional polishing methods, only silane-SiO2 and Optiglaze coated groups presented a clinically acceptable color change (ΔE<3.7) in all solutions over the period of immersion. Silane-SiO2 coated groups showed the lowest Ra value but not statistically significant difference from other groups.

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Introduction

Provisional prosthodontic restorations are used before the definitive restorations are delivered to the patients. The optimum provisional restorations must provide function, comfort, color stability, durability, good marginal adaptation, adequate retention and resistance, ease to handle, ability to repair and reline, biocompatibility, thermal insulation, and

preservation of periodontal health.[1,2] Polymethyl methacrylate (PMMA) based acrylic resin is widely used, because of its ease of polish, good marginal adaptability, and relatively inexpensive. However, the exothermic reaction, polymerization shrinkage, pulpal irritation, and poor wear resistance of the material are challenges.[2]

Discoloration of provisional materials may lead to a problem, especially in the esthetic area. The materials should maintain the initial color throughout the treatment. The color change is multifactorial and typically related to insufficient polymerization, water sorption, oral hygiene, and surface smoothness of the restoration. Coffee, tea, juice, and other colored liquids, as well as the length of time a staining solution is submerged, all contribute to discoloration.[1,3] To finish and polish interim materials, many procedures have been applied. Conventionally, after completing with burs and abrasive stones, polishing is performed using water and fine pumice, polishing paste, or liquid polish containing aluminum oxide particles. Surface sealant agents have been developed to reduce surface porosity and provide smooth surfaces. However, the effectiveness of these agents over the long term remains unknown.[1]

The technology of SiO_2 nanocomposite film coating for dental materials was introduced. By coating the denture base with SiO_2 nanocomposite film, the denture base became more hydrophobic and C. Albicans accumulation was reduced. The SiO_2 nanocomposite coating also increased the hardness of polymethyl methacrylate artificial teeth, comparable to composite resin artificial teeth. The potential application of nanocomposite films to various dental materials is currently being investigated.[4]

The purpose of this study was to evaluate the effectiveness of silane-SiO_2 film coating on color stability and surface roughness of provisional fixed prosthodontic material compared to three commercial surface coating agents. The first null hypothesis was that the silane-SiO_2 film coating would have no different effect on the color stability of provisional prosthodontic material. The second null hypothesis was that the effect of silane-SiO_2 film coating would not affect the surface roughness of provisional prosthodontic material from other commercial surface coating agents.

Materials and methods

One hundred sixty auto-polymerized polymethyl methacrylate disk-shaped specimens (15 mm in diameter and 1 mm in thickness) were fabricated by using stainless steel mold according to the manufacturer's instructions (Unifast Trad; GC America Inc). All specimens were polished with 600, 800,1000, and 2000 grit silicon carbide abrasive paper. The specimens were randomly divided into 5 groups according to surface coating procedures: control (no treatment) and four surface coating as shown in Table 1.

Group	Product	Composition	Manufacturer
	Unifast Trad	Powder: Methyl methacrylate and ethyl methacrylate copolymer Liquid: Methyl methacrylate, butylated hydroxytoluene, hydroquinone	GC America Inc
Ct	Non-coat	NA	NA
Ss	Silane-SiO₂	Methyltrimethoxysilane	Yuda Chemical Industry Co Ltd
Ps	Palaseal	Methyl methacrylate, tris(2-hydroxyethyl)-isocyanurate-triacrylate, acrylized epoxy oligomer, acrylates, acrylized polysiloxane	Heraeus Kulzer GmbH
Bc	Biscover LV	Dipentaerythritolpentaacrylate, ethanol	Bisco Inц
Og	Optiglaze	Methyl methacrylate, multi-functional acrylate, silica filler, photo-inhibitor	GC Corp

Table 1. Surface coating materials tested.

In the preparation of silane-SiO_2 film coating, 7.5 g of methyltrimethoxysilane (MTMS) was mixed with 0.9 ml of acetic acid and 8.1g of SiO_2 nanoparticles. The specimens were cleaned with isopropanol for 30 seconds. A motorized dip coater was used to apply the film coating solution on the pretreated PMMA at a withdrawal speed of 30 cm/min. The specimen was prepolymerized at 65°C for 20 minutes and then at 110°C for 2 hours.[5] For the Palaseal, Biscover LV and Optiglaze groups, a soft brush was used to apply a thin, even layer in one direction. Twenty seconds after application, the coated specimens were polymerized with a light-emitting diode (LED) polymerization light (Bluephase N, Ivoclar) 40 seconds for Ps and Og and 30 seconds for Bc.

Surface roughness: R_a (n=8 per group) was evaluated through profilometer tracing (Talysurf series2; Rank Taylor Hobson Ltd) across the specimen surface at a 90-degree angle and analyzed with a computerized system (Image-Pro Plus 3.0; Media Cybernetic). Six different traces were performed along the length of each specimen. One specimen of each group,

surface morphology was observed by scanning electron microscope (SEM, JSM-6610LV; JEOL Ltd) and element composition was analyzed by energy dispersive spectroscopy (EDS) before and after immersion in distilled water for 30 days.

Color discoloration of specimens was determined by spectrophotometer (ColorFlex 45/0 V1.80; HunterLab) and the CIE Lab system. A total of 24 specimens of each group were stored in distilled water at 37°c ± 1°c for 24 hours to simulate the rehydration of the first day of service of provisional restoration in the oral environment. Specimens were randomly divided into 3 groups (n=8) and immersed in each solution at 37°c ± 1°c for 30 days. Three staining solutions (distilled water, tea and coffee) were used for the color stability test. Five prefabricated doses of tea (Lipton; Unilever) were immersed in 500 ml of boiling distilled water for 10 minutes to prepare the tea solution. The coffee solution was prepared by 15 g of coffee (Nescafe Gold; Nestle) dissolving in 500 ml of boiling distilled water. The solutions were filtered via filter paper after 10 minutes of stirring. The solutions were changed every 2 days throughout the test. Color measurements were made before immersion (T_0), after 1 day (T_1), 7 days (T_2), and 30 days (T_3). Before measurement, each specimen was ultrasonic cleaned in distilled water for 5 minutes, excess water was removed with tissue paper and specimens were allowed to dry. Each specimen was measured three times, the mean value was computed and used to calculate the color alterations (ΔE) with the formula[6]: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$

Statistical analyses were performed using statistical software (SPSS v26.0 for Windows; SPSS Inc). The data from the experiments are presented as the mean and standard deviation (SD). The Shapiro-Wilk test was used to assess the normality of the data. Repeated measure ANOVA was used to analyze the color stability (ΔE). Surface roughness (R_a), the data were analyzed using one-way ANOVA and followed by Bonferroni adjustment for multiple comparisons. Differences were considered as a statistical significance when p<.05.

Results

Considering the degree of color alteration, different surface sealants showed significant color changes in acrylic resin (P<.05). Ss group presented the lowest ΔE value in all conditions. Ps group showed the highest color change in the coffee solution and the Bc group showed the highest color alteration in distilled water and tea solution. All groups presented increased ΔE when increased immersion time. Ss exhibited no significant color change over 30 days when immersion in distilled water and coffee (Table 2-4).

Group / Time	Day1	Day7	Day30
Control	0.62 ± 0.23 a,b,A	0.87 ± 0.41 a,b,A	1.99 ± 0.56 a,B
Sliane-SiO2	0.25 ± 0.16 a,A	0.53 ± 0.22 a,A	0.81 ± 0.28 b,A
Palaseal	0.40 ± 0.12 a,b,A	0.73 ± 0.15 a,A	1.76 ± 0.41 a,b,B
Biscover LV	0.92 ± 0.57 b,A	1.43 ± 0.59 b,B	2.48 ± 1.16 a,C
Optiglaze	0.55 ± 0.36 a,b,A	0.67 ± 0.45 a,A	1.98 ± 0.53 a,B

Table 2. Mean ± SD ΔE values of the test groups (n=8) when immersion in distilled water.
*Within the same period (vertical column), the same superscript lowercase letters were no significant differences between groups (P>.05).
Within the same group (horizontal row), the same superscripts uppercase letters were no significant differences within the group (P>.05).

Group / Time	Day1	Day7	Day30
Control	0.78 ± 1.84 a,b,A	1.55 ± 0.39 a,B	3.83 ± 1.13 a,c,C
Sliane-SiO2	0.34 ± 0.15 a,A	0.54 ± 0.14 b,A	1.13 ± 0.40 b,B
Palaseal	0.82 ± 0.26 a,b,A	1.49 ± 0.26 a,B	3.84 ± 0.50 a,c,C
Biscover LV	0.99 ± 0.57 b,A	1.87 ± 0.58 a,B	4.58 ± 0.53 a,C
Optiglaze	0.62 ± 0.20 a,b,A	1.28 ± 0.29 a,B	3.52 ± 0.15 c,C

Table 3. Mean ± SD ΔE values of the test groups (n=8) when immersion in tea solution.
*Within the same period (vertical column), the same superscript lowercase letters were no significant differences between groups (P>.05).
Within the same group (horizontal row), the same superscripts uppercase letters were no significant differences within the group (P>.05).

Group / Time	Day1	Day7	Day30
Control	1.15 ± 0.50 a,A	2.34 ± 0.60 a,B	2.72 ±0.57 a,B
Sliane-SiO2	0.34 ± 0.14 b,A	0.60 ± 0.12 b,A	0.82 ± 0.20 b,A
Palaseal	2.03 ± 0.55 c,A	4.26 ± 0.68 c,B	7.43 ± 1.29 c,C
Biscover LV	1.12 ± 0.49 a,A	3.50 ± 0.97 d,B	5.42 ± 0.82 d,C
Optiglaze	1.03 ± 0.32 a,A	1.95 ± 0.36 a,B	3.42 ± 0.67 a,C

Table 4. Mean ± SD ΔE values of the test groups (n=8) when immersion in coffee solution.

One-way ANOVA was used to analyze the roughness measurement. The Ra value results for each group were not statically significant (P>.05) (Figure 1). The mean R_a value for all groups ranged from 0.201 to 0.264. The highest R_a value was observed in the Ps group

(0.264 µm) and the lowest R_a value was determined for the Ss group (0.201 µm).

SEM images of the provisional material surface in each group before and after immersion in distilled water were shown in Figures 2-3. Before immersion, the uncoated acrylic resin presented a rougher surface and scratches than the other coated groups. Coated specimens (Ss, Ps, Bc, Og) revealed more smooth and regular surfaces. Thirty days after immersion in distilled water, control specimens showed markedly rougher and more irregular surfaces. Porosities and irregular surfaces were presented in the Ps specimen. Bc specimen presented a rougher surface, similarly, Og specimens presented various shallow pits on the surface. While Ss coated specimens, no marked change was observed. Results of the EDS analysis of each group before and after immersion in distilled water for 30 days are shown in Table 5.

Group	Element (%wt)		
		Before immersion	After immersion
Ct	C	73.40	C 78.22
	O	26.96	O 21.78
Ss	C	16.80	C 14.03
	O	44.36	O 44.88
	Na	0.22	Na 0.26
	Si	38.62	Si 40.83
Ps	C	67.05	C 65.95
	O	32.47	O 33.34
	P	0.33	P 0.33
	Si	0.15	Si 0.38
Bc	C	64.55	C 64.16
	O	35.45	O 29.54
Og	C	53.84	C 61.15
	O	38.95	O 35.50
	P	0.30	P 0.37
	Si	6.91	Si 2.98

Table 5. EDS analysis of the test group before and after immersion in distilled water for 30 days.
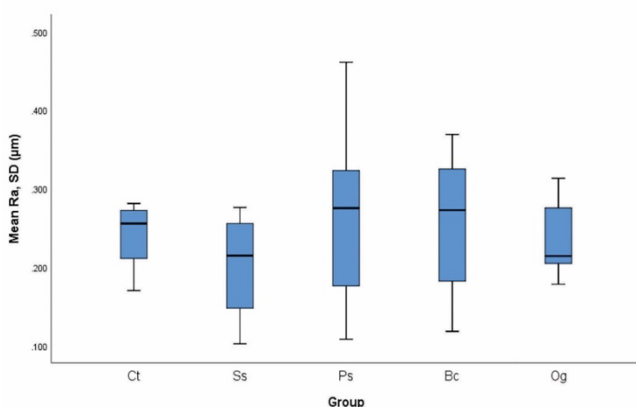

Figure 1. Mean R_a ± SD value of test groups.
Discussion

The first null hypothesis was rejected because the silane-SiO_2 film coating significantly affected on color stability of provisional prosthodontic material from other commercial surface coating agents. The second null hypothesis was accepted that the effect of silane-SiO_2 film coating was no statistically significant effect on the surface roughness of provisional prosthodontic material.
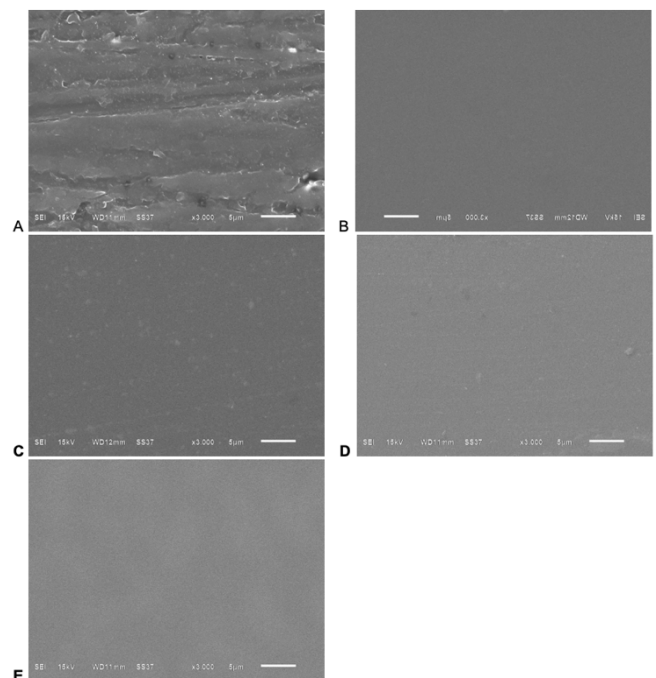

Figure 2. Scanning electron micrograph analysis (x3000 magnification) of provisional material before immersion. A, uncoated; B, silane-SiO_2; C, Palaseal; D, Biscover LV; and E, Optiglaze coated.

Color discoloration can be evaluated visually or through color measurement instruments. In objective measurement, the ΔE value represents the color change of materials. Several studies have reported the various ΔE value thresholds observed by the human eye. Johnston and Kao, assessed appearance matches using visual observation and clinical colorimetry. The average color difference between comparison teeth classified as a match in the oral environment was 3.7 of ΔE.[14] In the present study, the color change above the 3.7 ΔE value is referred to as clinically unacceptable, and below 3.7 is acceptable. After 30 days of immersion in distilled water, all provisional materials showed color change (ΔE) below 3.7

while immersed in the tea, ΔE values of all groups were above 3.7 except for Ss and Og groups. In the coffee solution, the ΔE value of Ct, Ss, and Og groups was below 3.7.
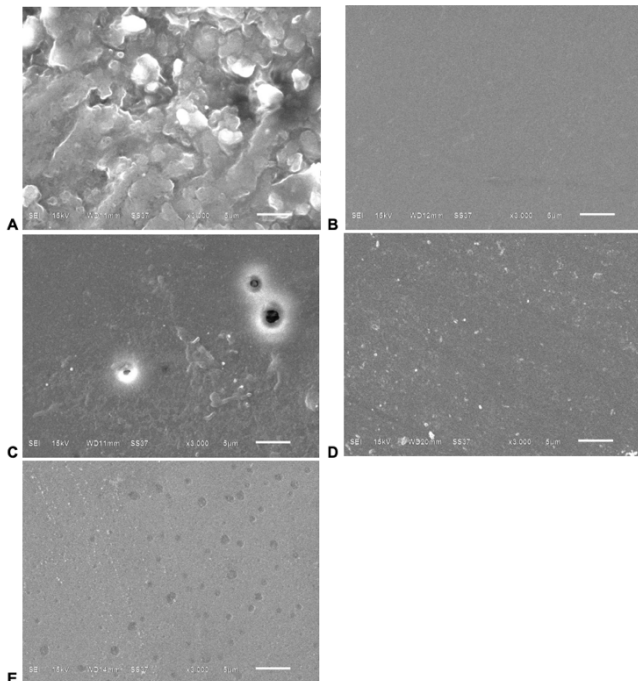

Figure 3. Scanning electron micrograph analysis (x3000 magnification) of provisional material after immersion in distilled water for 30 days. A, uncoated; B, silane-SiO_2; C, Palaseal; D, Biscover LV; and E, Optiglaze coated.

At 30 days of immersion time, all groups showed significant color alteration when compared to initial in all solutions except Ss that were immersed in distilled water and coffee solution were no significant color changes over the immersion period. Long immersion time may debond the surface coating material or fall off the filler particles of coating materials, then increase the surface roughness that could allow the pigment to penetrate or discolor the provisional restorative materials.[1,3] The polymer resin network can be disturbed by water penetrating. Furthermore, water can function as a plasticizer, softening the polymeric chains and causing hydrolytic degradation.[15]

Silane-SiO_2 film characterizes by hybrid hard-coating nanocomposite film, composes of hydrolyzed methyltrimethoxysilane and SiO_2 nanoparticles (20nm). A methyl group is an organofunctional group, which is hydrophobic. Moreover, silane-SiO_2 film has an alkoxy group that forms permanent chemical bonding on the substrate with a crosslink network and bonds on the surface of nanoparticles, providing the film strength. EDS analysis found about 40%wt Si elements in the Ss specimen both before and after being immersion in distilled water that may provide surface smoothness and less color change of materials.[5,16] Palaseal coated acrylic resin showed unacceptable color change (above 3.7 of ΔE value) when immersed for 30 days in tea and 7, 30 days in coffee solution and presented various surface roughness values, may have been caused by too high viscosity of fluid which composed of ethyl-cyanoacrylate that polarizes, tends to hydrolysis and insufficient resistance to abrasion of material.[17] Biscover LV is a dipentaerythritolpentaacrylate compound,[7] light cure resin with a low amount of filler particles. Guler et al reported that the use of a liquid polishing system seemed to increase the staining of specimens.[18] Doray et al informed that the content of sealant materials affected the color stability.[19] Glaze materials containing ethoxylated bisphenol-A dimethacrylate were less stain-resistant than methacrylate- or dimethacrylate-containing glaze materials. The stain resistance of the dipentaerythritolpentaacrylate-containing Bc sealant agent was lower than the Ps and Og-containing methacrylate or PMMA.[19] According to the present study, ΔE values of Bc specimens were highest when immersed in distilled water and tea solution. Optiglaze is a PMMA-based glaze material composed of silica filler. EDS analysis found that Og is composed of the Si element which is less favorable to stain. SEM image after immersion in the distilled water presented various shallow pits on the surface that may infer the loss of the silica filler overtime as the Si component was reduced (Fig. 3E) (Table 5).

In this study, silicon carbide abrasive paper with 600, 800, 1000, and 2000 grit was used to polish the specimens following to method of the previous study.[10] According to Eriko T et al, they investigated the influence of abrasive particle size on surface properties of flowable composites and found that the surface roughness of the composite became stable when polishing particles of less than 12 μm were used. To attain a satisfactory surface roughness and gloss, polishing should be completed with particles less than 9 μm.[11] The average particle size of silicon carbide paper with 600, 800, 1000 and 2000 grit

was 30, 20, 15, and 9 µm respectively based on ISO 8486-1:1996.[12]

Before immersion in distilled water, the Ra value of all specimens ranged between 0.201 and 0.264 µm. These values were less than 10 µm, the limit of clinical detectability identified by Kaplan et al.[7] The mean Ra value of the silane-SiO_2 coated group was 0.201 µm that approximates the threshold Ra of 0.2 µm which reduced plaque formation.[8] The application of surface coating materials was not statistically significant resulting in lower Ra values compared with the control group as Dede et al study.[9] SEM images displayed that a smoother surface could be obtained by applying surface coating agents than with conventional methods. Surface coating agents are recommended for improving the optimal properties such as surface smoothness by filling the micro-defect or porosity that forms after polishing procedures. However, the surface coating agents can lead the problems such as weak retention of the underlying material, low abrasive resistance and uneven spreading from the viscosity of the material or coating technique, resulting in poor surface quality.[1]

After immersion in distilled water for 30 days, SEM images of Ct, Ss, Ps, Bc, and Og specimens presented obviously irregular, porous, and rough surfaces (Fig3A-E). These may result from hydrolytic degradation and loss of filler particles. The film coating that has a large filler particle size will decrease the amount of filler content, resulting in increased surface roughness of materials. Therefore, an increase in the filler particle sizes would result in surface irregularity and cause discoloration.[5] On the other hand, fine particle size will result in surface smoothness.[13]

This in vitro study had some limitations. Only one type, a brand of provisional material was evaluated and the technique of silane-SiO_2 coating was different from other commercial surface coating agents. Silane-SiO_2 nanocomposite film coating is a practical and reasonable cost, can be processed in dental laboratories and dental clinics. However, the method should be developed to be more simple in further study.

Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. Silane-SiO_2 film-coated acrylic resin exhibited the most color stability compared to commercial surface coating agents and conventional polishing methods.
2. Silane-SiO_2 and Optiglaze coated groups presented a clinically acceptable ($\Delta E < 3.7$) color change in all solutions over the period of immersion.
3. Silane-SiO_2 coated groups showed the lowest Ra value but not statistically significant difference from other groups.

Declaration of Interest

The authors report no conflict of interest.

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