

Effects of different food colorants and polishing techniques on color stability of provisional prosthetic materials

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The main objective was to investigate the effects of different polishing techniques on the color stability of provisional prosthetic materials upon exposure to different staining agents by mimicking the oral environment *in vitro*. Fifty-six cylindrical specimens were prepared for each type of material: bis-acryl and light-polymerized composite resins, and methyl methacrylate- and ethyl methacrylate-based resins. The specimens were polished using seven different polishing techniques and then immersed in four different staining agents. Color was measured with a spectrophotometer before and after immersion, and color changes (ΔE) were calculated. The effects of the type of provisional material, polishing procedure, staining agent, and their interactions on color stability were significant ($p < 0.05$). Amongst these factors, the staining agent exerted the strongest effect on color stability. Amongst the provisional materials tested, methacrylate-based resins exhibited the highest color stability irrespective of polishing technique and staining agent.

Keywords: Color stability, Provisional prostheses, Food colorants

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INTRODUCTION

A provisional restoration could be defined as an interim dental prosthesis that maintains esthetics, provides masticating surfaces, and protects the hard and soft tissues prior to the delivery of the final prosthesis. In light of these roles and purposes, provisional restorations must therefore meet an array of diverse but interrelated criteria, which can be broadly classified into mechanical, biological, and esthetic requirements¹. On the esthetic requirement, the poor appearance of a prepared tooth or implant abutment should be concealed by imitating and maintaining the essential properties of natural teeth and gingiva, in terms of size, position, shape, color, surface texture, and translucency².

In practice, the use of provisional restorations could extend from several days to half a year or even more³. This means that poor-quality provisional restorations may lead to treatment complications, patient dissatisfaction, and perhaps even additional expenses for replacement. One pertinent aspect of quality is the color stability of the dental restorative material, which depends on several factors such as degree of conversion^{4,5}, water sorption^{6,7}, chemical reactivity^{8,9}, diet¹⁰⁻¹², oral hygiene^{13,14}, and surface roughness^{12,15-19}. Besides, the color change of provisional restorations may be related to poor biocompatibility and decreased mechanical properties¹⁸.

On assessment of color changes, visual inspection is a subjective physiological and psychological process. In contrast, the spectrophotometer, when used as a color evaluation device, not only eliminates subjective interpretations but also enables small color differences to be identified²⁰. The CIE (*Commission Internationale*

de l'Eclairage) $L^*a^*b^*$ color system is a uniform color scale that covers all the colors visible to the human eye, and is hence suitable for perceptual studies of color differences in dental materials²¹. Using the CIE $L^*a^*b^*$ color system, different thresholds of color change (ΔE) values that produce visually perceptible differences have been reported in a number of studies²²⁻²⁶. Generally, the color difference (ΔE) value of 3.7 or more is considered as visually perceptible and clinically unacceptable^{11,25,26}.

In tandem with the great variety of provisional prosthetic materials available on the market is the commercial availability of different surface processing techniques. However, few manufacturers offer recommendations on the optimal polishing method for their products. Similarly in the realm of research studies, scarce data is available on the effects of different types of materials, polishing techniques, and food colorants on the color stability of provisional prosthetic materials^{18,27,28}.

The purpose of this study, therefore, was to investigate the effects of different polishing techniques on the color stability of several provisional prosthetic materials upon their exposure to different staining agents by mimicking the oral environment *in vitro*. The null hypothesis tested was that the material type, polishing technique, and staining agent do not affect the color stability of the materials under study.

MATERIALS AND METHODS

Provisional prosthetic materials

Seven commonly used provisional prosthetic materials were investigated in this study, as shown in Table 1. These materials could be categorized as: methyl methacrylate- and ethyl methacrylate-based resins, and

Table 1 Provisional prosthetic materials used in this study

Product	Manufacturer	Resin type
Dentalon Plus (Liquid: Batch # 010205; Powder: Batch # 010301)	Heraeus Kulzer, Hanau, Germany	Ethyl-methacrylate-based resin
Unifast Trad (Liquid: Batch # 339291; Powder: Batch # 339104)	GC Dental Products, Aichi, Japan	Methyl-methacrylate-based resin
Luxatemp Fluorescence (Batch # 560394)	DMG, Hamburg, Germany	Bis-acryl composite resin
Prottemp 3 Garant (Batch # B 286620; C 284362)	3M ESPE, Seefeld, Germany	Bis-acryl composite resin
Revotek (Batch # 0705102)	GC Dental Products, Aichi, Japan	Light-polymerized composite resin
RxCreate (Batch # 220607)	Dental Life Sciences, Ince, Wigan, UK	Light-polymerized composite resin
Structur Premium (Batch # 792365)	Voco, Cuxhaven, Germany	Bis-acryl composite resin

bis-acryl and light-polymerized composite resins.

Specimen preparation

Using a metal mold, 56 cylindrical specimens of 10 mm diameter and 2 mm height were prepared for each material. All specimens were prepared according to each material manufacturer's instructions. For the light-polymerized specimens, they were cured using a light curing unit (Elipar FreeLight 2, 3M ESPE, Seefeld, Germany) with a 1,200 mW/cm² light intensity for 20 seconds on each side. To ensure uniform surface roughness for all the specimens, it was realized by applying a green acrylic polisher (Hager & Meisinger, Neuss, Germany) for 10 seconds at 1,500 rpm on both sides of each specimen.

For each material, all the specimens were divided into 28 groups of two specimens each, according to the different combinations of polishing technique ($n=7$) and staining agent ($n=4$) (Table 2). Details of the polishing and coating systems used in this study are given in Table 3.

Polishing and surface coating techniques

For all the polishing techniques employed in this study, both sides of each specimen were uniformly processed according to the designated method.

1. Meisinger polishing set

The Meisinger (Hager & Meisinger) polishers were used in the following order: coarse, medium, and fine grits. Each polisher was applied on both sides of the specimens for 20 seconds each at 15,000 rpm.

2. Enhance finishing and polishing system

The aluminum oxide disks of Enhance (Dentsply/Caulk, Milford, DE, USA) were used for 30 seconds on each side of the specimens, with the subsequent application

of a fine and then an extra-fine polishing paste.

3. Glaze & Bond varnish

Surface coating was applied on the designated specimens using a light-curing varnish, Glaze & Bond (DMG, Hamburg, Germany). Each side was light-cured for 20 seconds as recommended by the manufacturer.

In addition, a test group consisted of specimens that were polished using the Enhance system (Dentsply/Caulk) followed by surface coating using the Glaze & Bond varnish.

4. RxCreate diamond polishing paste

For this group of specimens, RxCreate diamond polishing paste (Dental Life Sciences, Ince, Wigan, UK) was applied for 1 minute to both sides of the specimens.

5. Pumice powder with goat hair wheel

A pumice powder (Poliresin[®], Siladent Dr. Böhme & Schöps GmbH, Goslar, Germany) was applied using a goat hair wheel (Hager & Meisinger) at 3,000 rpm for 2 minutes on each side of the specimens. This was followed with the application of a polishing paste (Universal Polishing Paste, Ivoclar Vivadent, Schaan, Liechtenstein).

On the other hand, unpolished specimens served as a control.

Color measurement using CIE L*a*b* color space

Specimens were stored in distilled water for 24 hours at 37°C. This was done to mimic the first day of service in the oral environment²⁹⁻³¹. A custom-made silicon (Panasil[®] putty, Kettenbach GmbH, Eschenburg, Germany) holder (Fig. 1) was used to hold the specimen during color measurement with a spectrophotometer (VITA Easyshade, VITA Zahnfabrik, Bäd Sackingen, Germany) as well as to minimize the influence of

Table 2 A sample listing of the test groups for the Revotek material

Product	Type of polishing technique/coating	Staining agent	Group code
Revotek	Control	Distilled water	RC1
		Food colorant	RC2
		Coffee	RC3
		Red wine	RC4
	Meisinger polishing set	Distilled water	RM1
		Food colorant	RM2
		Coffee	RM3
		Red wine	RM4
	Enhance finishing and polishing set	Distilled water	RE1
		Food colorant	RE2
		Coffee	RE3
		Red wine	RE4
	Glazing	Distilled water	RG1
		Food colorant	RG2
		Coffee	RG3
		Red wine	RG4
Enhance finishing and polishing set with subsequent glazing	Distilled water	REg1	
	Food colorant	REg2	
	Coffee	REg3	
	Red wine	REg4	
RxCreate diamond polishing paste	Distilled water	RRx1	
	Food colorant	RRx2	
	Coffee	RRx3	
	Red wine	RRx4	
Laboratory: goat hair wheel with pumice powder	Distilled water	RL1	
	Food colorant	RL2	
	Coffee	RL3	
	Red wine	RL4	

Table 3 Polishing/coating systems used in this study

Product	Manufacturer	Composition
Meisinger polishing set (green, gray, yellow polishers)	Hager & Meisinger, Neuss, Germany	Polysiloxane and indian rubber impregnated with silicon carbide particles
Enhance Finishing and Polishing System Polishing discs: Batch # 0708201 Fine polishing paste: Batch # 070807 Extra Fine polishing paste: Batch # 070821	Dentsply/Caulk, Milford, DE, USA	Aluminum oxide disks (40 µm), fine (1 µm), and extrafine (0.3 µm) aluminum oxide pastes
Glaze & Bond (Batch # 589468)	DMG, Hamburg, Germany	Acrylic resin, methyl methacrylate
Rx polishing	Dental Life Sciences, Ince, Wigan, UK	Diamond-based paste
Goat Hair Wheel	Hager & Meisinger, Neuss, Germany	Goat hair
Poliresin	Siladent Dr. Böhme & Schöps GmbH, Goslar, Germany	Pumice powder
Universal Polishing Paste	Ivoclar Vivadent, Schaan, Liechtenstein	Paste of aluminum oxide

external light through the edge of the specimen³².

Baseline CIE $L^*a^*b^*$ color coordinates were established using a spectrophotometer for every specimen before its exposure to a staining agent. To



Fig. 1 Spectrophotometer tip placed against a specimen in a custom-made silicone holder.

obtain the baseline color data, each side of a specimen was measured three times. The CIE $L^*a^*b^*$ color space illustrates all the colors perceptible to the human eye in the visible light range using a three-dimensional representation. L^* describes the lightness of an object; a^* value indicates the color position between red and green, whereas b^* indicates the color position between yellow and blue³³. The spectrophotometer was calibrated during every color measurement session against a provided calibration block integrated into the machine.

Staining agents

Three staining agents were prepared for this study: coffee with sugar (Jacobs Krönung, Kraft Foods Inc., Northfield, IL, USA), red wine (Gran Vino Merlot 2005, Santa Helena, Santiago, Chile), and a mix of sunset yellow and quinoline yellow 3% dyes (Unifine, Puttershoek, Netherlands)³⁴. Distilled water was used as a control liquid.

For coffee as a staining agent, it was prepared by mixing 12 g of natural coffee powder and 10 g of white sugar with 200 ml of boiling water. For the food colorants, 3 g of dye was mixed with 100 ml of distilled

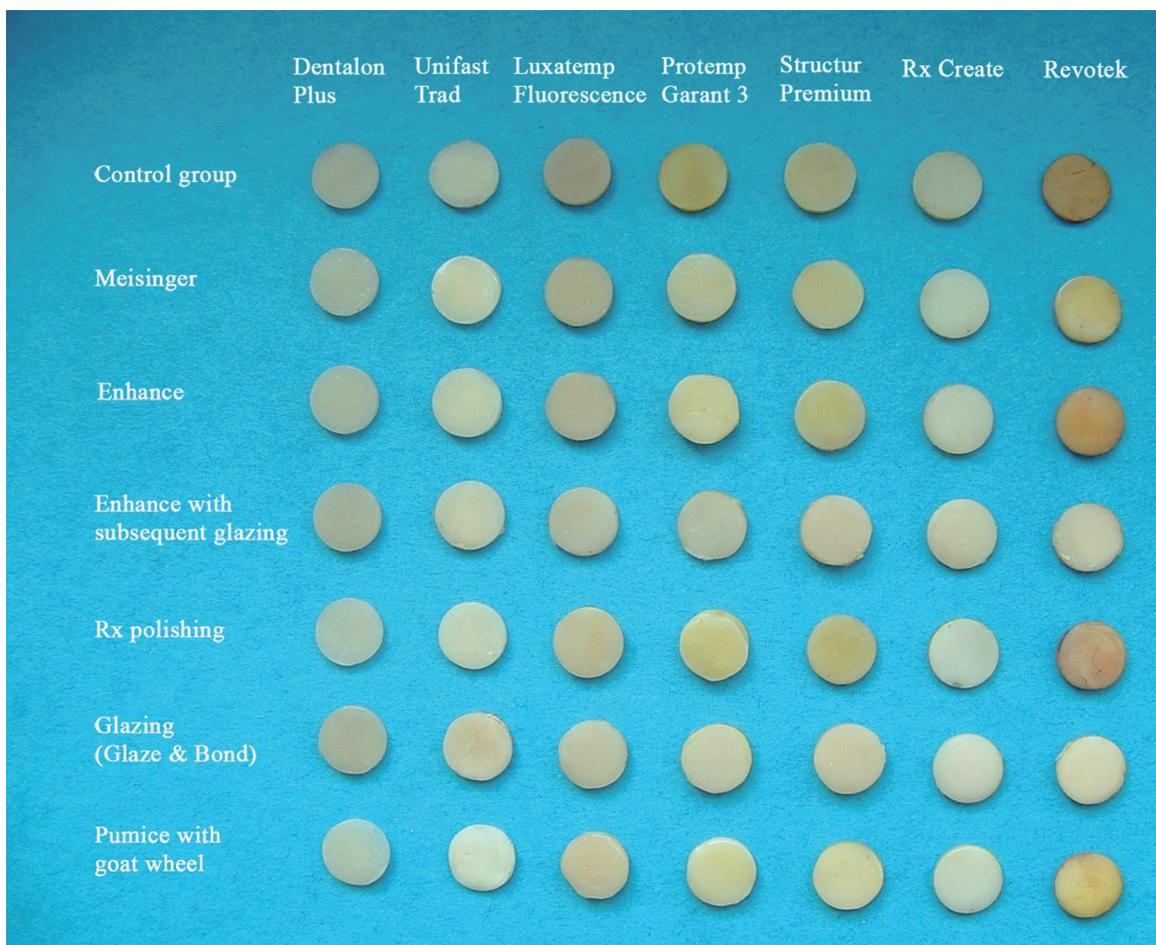


Fig. 2 Specimens after immersion in red wine for 7 days.

water. Specimens were immersed in the designated staining agents for 7 days and stored in bath at 37°C (Bandelin Sonorex, Schalltec GmbH, Mörfelden-Walldorf, Germany).

After 7 days, the specimens were cleaned using an electric toothbrush (Colgate Motion, Colgate-Palmolive, NY, USA) with toothpaste (Colgate Total, Colgate-Palmolive, NY, USA) for 10 seconds on each side of the specimens. This was followed with gentle rinsing in water and drying with a paper towel (Fig. 2). Each specimen's color was evaluated in the same manner prior to exposure. ΔE , known as the Euclidean distance between two points in a three-dimensional color space, was calculated from the mean values of ΔL^* , Δa^* , and Δb^* using the following formula:

$$\Delta E^* = [(L_1^* - L_0^*)^2 + (a_1^* - a_0^*)^2 + (b_1^* - b_0^*)^2]^{1/2}$$

Statistical analysis

The effects of material, polishing technique, and staining agent on color stability were evaluated using three-way ANOVA with a statistical software (SPSS 16.0.1 for Windows, SPSS Inc., Chicago, IL, USA). Tukey's HSD *post hoc* analysis was used to define statistically significant differences among the groups. Statistical significance was set at $p < 0.05$.

RESULTS

The effects of the primary factors of material type, polishing technique, and staining agent on color change are summarized in Table 4. According to three-way ANOVA, these primary factors and their interactions exerted statistically significant influence ($p < 0.05$) on color stability. The color changes (mean ΔE values) of provisional materials after exposure to different

staining agents are presented in Figs. 3–6 and Table 5.

After a 7-day immersion period in distilled water, only Protemp 3 Garant (3M ESPE) showed insignificant color changes ($\Delta E < 3.7$) after all types of polishing procedures. Similarly, Luxatemp Fluorescence (DMG, Hamburg, Germany) showed insignificant color changes except after glazing. On the other hand, Revotek (GC, Aichi, Japan) showed noticeable color changes after all types of polishing procedures except with Meisinger polishing set (Hager & Meisinger) and Glaze & Bond surface coating.

With the food colorant solution, no visible color changes were observed for Protemp 3 Garant (3M ESPE) and RxCreate (Dental Life Sciences, Ince, Wigan, UK) specimens for all the polishing procedures. On the other hand, Revotek (GC) specimens showed

Table 4 Effects of material type, polishing technique, and colorant on color change (ΔE)

Source	F-value	p
Material type	1106,470	0.000
Polishing	326,509	0.000
Colorant	3730,095	0.000
Material type + polishing	96,518	0.000
Material type + colorant	299,539	0.000
Polishing + colorant	89,051	0.000
Material type + polishing + colorant	39,929	0.000

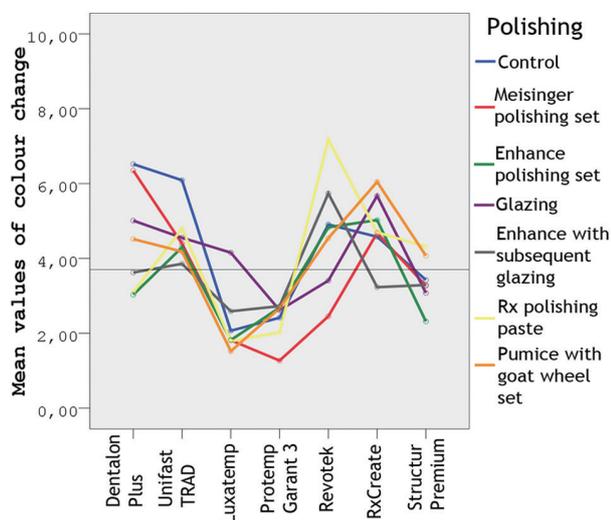


Fig. 3 Graphical representation of mean color changes (ΔE) in distilled water of all the provisional materials according to the polishing procedure.

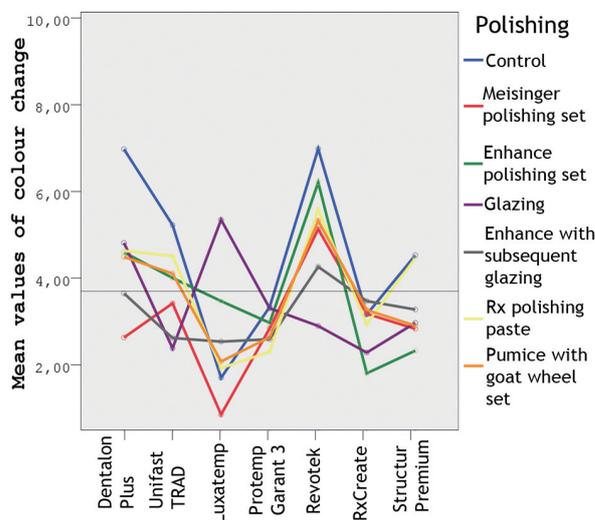


Fig. 4 Graphical representation of mean color changes (ΔE) in a mix of sunset yellow and quinoline yellow 3% solution of all the provisional materials according to the polishing procedure.

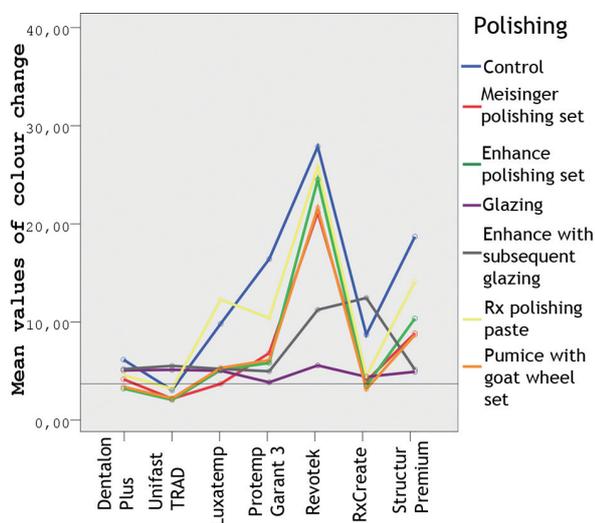


Fig. 5 Graphical representation of mean color changes (ΔE) in coffee with sugar of all the provisional materials according to the polishing procedure.

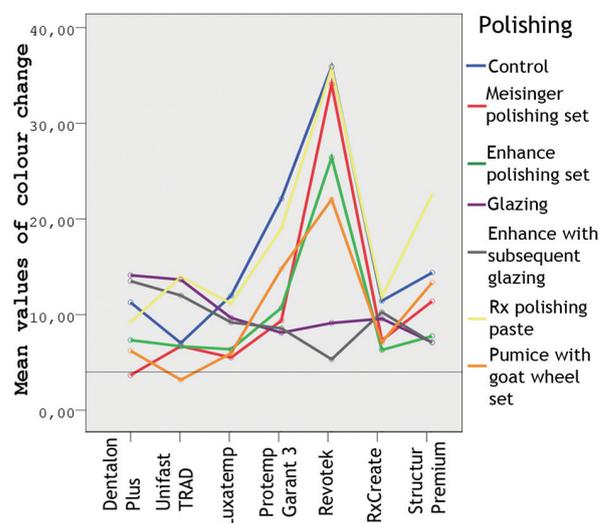


Fig. 6 Graphical representation of mean color changes (ΔE) in red wine of all the provisional materials according to the polishing procedure.

visually detectable ($\Delta E \geq 3.7$) color changes after all types of polishing procedures except after glazing. Upon comparison with immersion in distilled water, no statistically significant difference ($p=0.07$) was found between the color change values in distilled water and food colorant solution.

As for coffee with sugar, both Dentalon Plus (Heraeus Kulzer) and RxCreate (Dental Life Sciences) exhibited insignificant color change when applied with the Enhance finishing and polishing system (Dentsply/Caulk) or goat hair wheel with pumice powder. On the other hand, Unifast TRAD (GC, Aichi, Japan) showed no visible color change ($\Delta E \leq 3.2$) after all types of polishing procedures except after glazing and Enhance with subsequent glazing ($\Delta E \geq 5.1$).

After immersion in red wine, noticeable color changes were observed for all types of provisional materials irrespective of the polishing technique applied. Exceptions were found in Dentalon Plus (Heraeus Kulzer, Hanau, Germany) after polishing with Meisinger polishing set (Hager & Meisinger) ($\Delta E=3.6$) and in Unifast Trad (GC) after treatment with goat hair wheel and pumice powder ($\Delta E=3.2$).

DISCUSSION

This study revealed that the color stability of provisional prosthetic materials was significantly influenced by the material type, polishing technique, and staining agent. In light of these findings, the null hypothesis of this study was rejected.

According to statistical analysis results, the staining agent was the most significant factor for color change (F -value=3730), followed by material type (F -value=1106) and polishing technique (F -value=327) (Table 4). The clinical implication of these results is

that the selection of material type is more important than the surface treatment technique employed. However, if the dietary habits of the patient already present a potential discoloration risk to the provisional restoration, then the treatment option must take into consideration the appropriate type of provisional material combined with the optimum polishing technique.

There are many reasons why the surface of a restoration should be made as smooth as possible. It serves to ensure long-term esthetic success — including color stability, and it is also noteworthy that prosthetic material wear is partly determined by surface finishing (*i.e.*, polishing and/ or glazing). For these reasons, adequate finishing and subsequent polishing are key to fortifying a restoration against plaque accumulation, possible adsorption of stains, and increased material wear which could compromise the clinical performance of the whole restoration³⁵.

The staining of dental materials is the result of both extrinsic (surface roughness, poor oral hygiene, nutrition, and material wear) and intrinsic (filler and monomer composition, residual unpolymerized monomers resulting from incomplete polymerization) factors³⁶⁻³⁸. The mechanism of staining could be explained by both the adsorption and absorption of colorants³⁹, and the latter phenomenon of stain sorption is closely related to water sorption. A number of studies have reported that water absorption is influenced by factors such as filler content^{40,41}, presence of residual unpolymerized monomers, inclusion of air bubbles^{42,43}, and the cross-linking degree of resin molecules^{44,45}. In particular, incomplete polymerization might cause the physical properties of the resin material to deteriorate and microleakage to increase, thereby inducing color changes.

Table 5 Mean values and standard deviations (in parentheses) of color changes (ΔE) of provisional materials in different staining agents after 7 days of immersion

		Control	Meisinger polishers*	Enhance polishing system*	Glazing [#]	Enhance with glazing [#]	Rx polishing paste	Pumice with goat wheel set*
Dentalon Plus**	Distilled water (control)	6.5 (0.5)	6.3 (1.6)	3.0 (1.0)	5.0 (1.3)	3.6 (0.7)	3.1 (1.0)	4.5 (1.0)
	Food colorant	7.0 (1.5)	2.6 (1.0)	4.6 (1.5)	4.8 (1.2)	3.6 (1.2)	4.6 (0.4)	4.5 (0.7)
	Coffee with sugar	6.2 (0.5)	4.2 (1.8)	3.2 (1.4)	5.1 (0.9)	5.2 (0.4)	4.6 (1.8)	3.4 (1.3)
	Red wine	11.3 (4.6)	3.6 (0.9)	7.3 (1.4)	14.1 (1.7)	13.5 (1.0)	9.2 (3.8)	6.2 (1.4)
Unifast Trad ^{##}	Distilled water (control)	6.1 (2.1)	4.4 (2.3)	4.3 (1.0)	4.6 (2.7)	3.9 (0.6)	4.8 (2.2)	4.2 (0.6)
	Food colorant	5.2 (1.8)	3.4 (0.7)	4.0 (1.1)	2.4 (0.6)	2.6 (1.1)	4.5 (0.7)	4.1 (1.0)
	Coffee with sugar	3.0 (0.6)	2.2 (0.7)	2.1 (0.8)	5.1 (1.1)	5.5 (3.5)	3.2 (0.7)	2.2 (0.8)
	Red wine	7.0 (1.1)	6.7 (0.8)	6.7 (0.7)	13.6 (1.1)	12.0 (2.5)	13.9 (0.6)	3.2 (1.2)
Luxatemp Fluorescence ^{##}	Distilled water (control)	2.1 (0.7)	1.8 (1.1)	1.8 (0.6)	4.2 (0.4)	2.6 (1.9)	1.8 (0.6)	1.5 (0.4)
	Food colorant	1.7 (0.5)	0.9 (0.5)	3.5 (0.6)	5.3 (1.7)	2.5 (0.5)	1.9 (0.5)	2.1 (0.2)
	Coffee with sugar	9.8 (1.8)	3.7 (1.5)	5.1 (1.1)	5.0 (1.5)	5.2 (3.0)	12.3 (1.6)	5.3 (1.6)
	Red wine	12.0 (2.5)	5.5 (2.2)	6.4 (1.4)	9.7 (0.5)	9.2 (0.9)	11.2 (1.0)	6.0 (0.8)
Protemp 3 Garant	Distilled water (control)	2.4 (1.0)	1.3 (0.6)	2.7 (1.4)	2.6 (1.0)	2.7 (1.8)	2.0 (0.5)	2.7 (0.8)
	Food colorant	3.3 (2.0)	2.8 (0.9)	3.0 (1.2)	3.3 (2.3)	2.6 (0.7)	2.3 (0.7)	2.6 (1.1)
	Coffee with sugar	16.4 (1.8)	6.8 (2.3)	5.8 (0.8)	3.9 (0.8)	5.0 (0.9)	10.4 (4.9)	6.1 (1.3)
	Red wine	22.1 (2.4)	9.4 (1.2)	10.7 (2.6)	8.1 (0.8)	8.6 (1.3)	19.0 (1.7)	14.8 (3.9)
Revotek LC	Distilled water (control)	4.9 (2.1)	2.5 (1.0)	4.8 (1.5)	3.4 (0.9)	5.7 (0.9)	7.2 (2.4)	4.5 (0.8)
	Food colorant	7.0 (2.4)	5.1 (2.8)	6.2 (1.6)	2.9 (1.4)	4.3 (2.0)	5.6 (1.2)	5.3 (1.6)
	Coffee with sugar	27.9 (2.2)	21.2 (2.0)	24.5 (2.4)	5.6 (1.4)	11.2 (0.9)	25.8 (2.6)	21.6 (3.4)
	Red wine	35.9 (1.3)	34.1 (1.6)	26.4 (0.8)	9.1 (2.1)	5.3 (1.8)	35.7 (1.9)	22.0 (0.6)
RxCreate**	Distilled water (control)	4.6 (2.2)	4.7 (1.7)	5.0 (3.0)	5.7 (2.4)	3.2 (2.2)	4.7 (2.2)	6.0 (1.2)
	Food colorant	3.2 (0.4)	3.2 (1.7)	1.8 (0.7)	2.3 (1.2)	3.5 (0.6)	2.9 (0.7)	3.3 (1.3)
	Coffee with sugar	8.7 (2.5)	4.0 (1.2)	3.5 (1.1)	4.4 (1.5)	12.4 (0.7)	4.5 (1.5)	3.2 (2.5)
	Red wine	11.4 (2.0)	7.3 (0.8)	6.3 (0.7)	9.6 (1.0)	10.3 (1.3)	11.9 (0.9)	7.1 (1.2)
Structur Premium	Distilled water (control)	3.4 (0.8)	3.3 (0.8)	2.3 (0.8)	3.1 (0.7)	3.3 (0.7)	4.3 (1.3)	4.1 (1.1)
	Food colorant	4.5 (1.9)	2.8 (0.9)	2.3 (1.1)	3.0 (1.1)	3.3 (0.6)	4.5 (0.6)	2.9 (0.7)
	Coffee with sugar	18.7 (3.0)	8.9 (2.5)	10.4 (1.8)	4.9 (0.6)	5.1 (0.8)	14.1 (1.6)	8.7 (1.3)
	Red wine	14.4 (4.8)	11.4 (2.4)	7.8 (0.6)	7.1 (0.8)	7.1 (1.7)	22.6 (2.0)	13.4 (1.5)

*, #, **, ##: Indicate groups with no statistically significant differences ($p < 0.05$)

In the present study, immersion in distilled water resulted in visible color changes in most of the materials, although the ΔE values were below 7.2. Non-polished (control) specimens showed similar or lower ΔE values as compared to the polished ones. Meisinger polishers (Hager & Meisinger) tended to render the surface more resistant to discoloration. Notably, color change was minimal ($\Delta E=1.3$) when Protemp 3 Garant (3M ESPE) was surface-treated with Meisinger polishers (Hager & Meisinger). It has been

shown that water accumulation and photo-oxidation affected the internal colors of provisional restorative materials and changed their optical properties^{5,46-49}. Hence, these could be the reasons that were responsible for the color change of specimens after immersion in distilled water.

Similar results were obtained in food colorant solution ($\Delta E < 7$), whereby Luxatemp material (DMG) polished with Meisinger set (Hager & Meisinger) resulted in the minimum color change ($\Delta E=0.9$).

Typically, sunset yellow and quinoline yellow dyes are used at a concentration of 0.02% to 0.1%. However, according to manufacturers, the concentration of a colorant in some food products may reach 3%. These colorants are soluble in water and as they have electrostatic charges on their molecules, they may stain surfaces⁵⁰. Interestingly, there was no significant difference between the effects of distilled water and food colorant solution. It was probable that the electrostatic forces played an insignificant role in the staining process because of the less hydrophilic nature of the materials. Consequently, the dye molecules were unable to penetrate deeper into the resin matrix due to water absorption after 24 hours of hydration^{51,52}. The clinical implication of this finding is to refrain from consuming colored beverages for 24 hours following the cementation of provisional restorations.

Conversely, substantial increases in ΔE value were noted under the effects of coffee with sugar and red wine. The only exception was Unifast Trad (GC) polished in the laboratory, which showed the least discoloration in both red wine and coffee with sugar. These results were in agreement with the findings of previous studies whereby red wine caused the most severe discoloration of provisional restorative materials^{29,53}. The mechanism behind discoloration by red wine and coffee may be surface adsorption and the absorption of colorant particles. According to some studies, the formation of a biofilm positively correlated with surface free energy, surface roughness, and hydrophobicity^{54,55}. Since surface roughness and geometrical irregularities are inevitable, bacteria are bound to attach or adhere to the restorative material surface and start forming a biofilm matrix composed of proteins, polysaccharides, DNA, RNA, and other cell components⁵⁶⁻⁵⁸. Moreover, polyphenol molecules are capable of binding to proteins as well as to artificial surfaces through adsorption^{59,60}. Therefore, to counter staining and to ensure color stability, oral hygiene plays an important role because organic acids that are produced by plaque bacteria tend to soften restorative resins and cause pronounced surface staining¹³. Besides, the influence of ethanol on the properties of provisional prosthetic materials cannot be underestimated. It has been shown that various provisional materials were significantly softened by aqueous ethanol solutions⁶¹.

In this study, bis-acryl composite resins, as compared to methyl/ethyl methacrylates, exhibited more significant color changes in coffee with sugar and in red wine. In another study¹⁷ which employed different polishing techniques, methacrylate-based resins were found to obtain a smoother surface than bis-acryl composites. This could be attributed to the more homogeneous composition of the methacrylate-based resin materials *versus* bis-acryl composite materials. As for light-cured composite materials, their color stability additionally depends on the photoinitiator component, resin matrix composition, light-curing device, and irradiation time⁶². In the present study,

Revotek (GC) showed the lowest color stability in coffee and red wine, irrespective of the polishing technique applied.

Surface glazing caused a similar color change in all the test groups, irrespective of the material type. This was probably because the whole surface was covered with glaze and only the resin matrix reacted with the extrinsic factors. With surface glazing, the surface coating material — in addition to the benefits of the polishing procedure — augmented the staining resistance by reducing the porosity of the surface⁶³. On the other hand, according to Lambrechts and Vanherle⁶⁴, glazing material was lost over time from the superficial pores that acted as retentive cavities; therefore, the improved resistance to staining might be of only temporary benefit. The major goal of glazing is to produce a smooth surface, and although surface smoothness contributes to color stability, a positive correlation between surface roughness and staining is not always present^{65,66}.

In the present study, a few factors could not be assessed *in vitro*. The experimental specimens had flat surfaces, whereas in clinical situations anatomical grooves and pits are imitated on the prosthetic restorations — thus adequate polishing and plaque control could be harder to accomplish. Secondly, in the oral environment, a prosthetic restoration is subjected to diverse harsh influences and conditions: saliva containing various proteins and enzymes, wide variety of food products and beverages, great extremes of temperature for food and drink, smoking, bad oral hygiene habits, and functional and parafunctional loading. Taken together, all these factors contribute to color changes. Therefore, a more comprehensive strategy should be developed to test the oral environment influences on the color stability of provisional prosthetic materials.

CONCLUSIONS

Within the limitations of this study, it could be concluded that:

1. Staining agent had the highest impact on the color stability of provisional prosthetic materials, followed by the type of material and the polishing/coating method.
2. Amongst the staining agents tested, red wine caused the greatest color change.
3. The highest color stability was shown by methacrylate-based resins, namely Unifast Trad and Dentalon Plus, irrespective of the polishing technique used and the staining agent to which they were exposed. Conversely, the light-polymerized composite, Revotek, showed the lowest color stability among all the materials tested.
4. For the unpolished specimens, their color stability was the lowest irrespective of material type. However, glazing contributed significantly to color stability.

5. For the surface-treated specimens, the best combination between a provisional material and polishing technique was Unifast Trad and goat hair wheel with pumice powder.

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