Effect of different surface treatment methods on the surface roughness and color stability of interim prosthodontic materials

Aysegül Köroğlu, DDS, PhD, Onur Sahin, DDS, PhD, Doğu Ömür Dede, DDS, PhD, and Burak Yılmaz, DDS, PhD

Interim crown restorations provide function and comfort, adequate oral hygiene, pulpal protection and thermal insulation, stabilization against undesired tooth movements, and prevention of gingival overgrowth. They may also be used for diagnostic purposes.1-4

The materials available for fabricating interim crowns by either direct or indirect techniques are poly(methyl methacrylate) (PMMA), polyethyl methacrylate (PEMA), polyvinyl methacrylate (PVMA), urethane dimethacrylate (UDMA), bis-acryl composite resin, and composite resin.1,2,5,6 Acrylic resins are low-cost materials that can be easily smoothed and polished; however, the exothermic polymerization reaction and polymerization shrinkage of the material present challenges.7-9 The development of bis-acryl materials has helped to eliminate some of these problems. However, their higher cost and low resistance to deformation are disadvantages.9,10

ABSTRACT

Statement of problem. The effects of surface sealant agents on the surface roughness and color stability of interim crown materials are unknown.

Purpose. The purpose of this in vitro study was to evaluate the effects of different polishing methods on the surface roughness and color stability of 4 interim crown materials.

Material and methods. A total of 160 specimens were fabricated from 2 poly(methyl methacrylate) (PMMA; Tab 2000, Dentalon Plus) and 2 bis-acryl (Tempo fit, Protemp 4) interim crown materials and divided into 4 groups (n=10) according to applied surface treatment procedures: conventional polishing (control) and 3 surface sealant (Palaseal, Optiglaze, Biscover) coupling methods. Surface roughness (Ra) values were measured with a profilometer. Color parameters were measured with a spectrophotometer before and after staining in coffee. Color differences (CIEDE 2000 [D[E00]) were calculated. Data were statistically analyzed with 2-way ANOVA and the Tukey honest significant differences test (α=.05).

Results. The Ra values of Tempo fit with Biscover were significantly lower than their control group, Tab 2000 and Dentalon Plus control groups (P<.05). The highest D[E00 was calculated for Tempo fit control (P<.05). The Dentalon Plus control group had significantly higher D[E00 values than the other groups, except for the Tempo fit and Tab 2000 control groups. The Tab 2000 control D[E00 was significantly higher than the other groups, except for Dentalon Plus with Palaseal and Dentalon Plus with Optiglaze.

Conclusions. All specimens had a surface roughness higher than the plaque accumulation threshold (0.20 μm). Smoother surfaces were observed for Tempo fit with Biscover when compared with the Tempo fit control. The color change observed with the Dentalon Plus, Tab 2000, and Tempo fit control groups was clinically unacceptable. Nonperceivable color changes were seen with Protemp 4 with Optiglaze, Tempo fit with Optiglaze, and Tempo fit with Biscover. Perceivable but clinically acceptable color changes were observed when sealants were used for all other test groups and Protemp 4 control. (J Prosthet Dent 2016;115:447-455)
surfaces are more inclined to plaque accumulation. R₄ average is a commonly reported parameter for roughness. R₄max value is defined as the maximum of the peak-to-valley heights of the measured section. Recent in vivo studies have suggested that a “threshold Ra” value above 0.2 μm in surface roughness is associated with increased plaque accumulation and bacterial retention.

Color stability is an important criterion when selecting an interim crown material. Color alteration is multifactorial and generally related to incomplete polymerization, water sorption, oral hygiene, and the surface smoothness of the restoration. Pigmented beverages such as coffee and tea also promote discoloration. Various techniques have been used to finish and polish interim materials. Conventionally, after finishing with burs and abrasive stones, a polish is obtained with water and fine pumice, polishing paste, or liquid polish that contains aluminum oxide particles. Recently, surface sealant agents have been introduced to minimize surface porosity and obtain smooth surfaces. However, the long-term performance of these agents is uncertain.

The purpose of this study was to evaluate different surface treatment methods on the surface roughness and color stability of interim crown materials. The null hypothesis of this study was that the surface sealant coupling techniques would have no effect upon the surface roughness and color stability of interim crown materials and that their effect would not vary depending on the type of resin material.

MATERIAL AND METHODS

Two autopolymerized polymethyl methacrylate and 2 bis-acryl composite resin–based interim crown materials were evaluated in this study (Table 1). Forty disk-shaped specimens (10 mm in diameter and 2 mm in thickness) were prepared for each resin material by using stainless steel molds. Materials were mixed according to the manufacturers’ instructions. The specimens were then divided into 4 groups (n=10) to provide different surface treatments as follows: 1 conventional laboratory polishing (control) and 3 surface sealant agent coupling methods. Power analysis showed that to detect a minimum significant difference in surface roughness of 0.774 μm (standard deviation [SD]=0.24) with β=.01 type II error, 5% type I error, and α=.05 probability level, a minimum of 9 specimens were necessary for each group to achieve a 95% confidence interval and 99% power. The surface-sealing agents used in this study are shown in Table 2.

All specimens were finished with a tungsten carbide bur (S274 190 060; Horico) and wet ground with a sanding machine (100 rpm for 15 seconds; Phoenix Beta; Buehler Ltd.) with 400-grit silicon carbide abrasive paper (English Abrasives). Control group specimens were polished with a slurry of coarse pumice (Isler Pomza; Isler Dental) and water with a bristle brush on a polishing lathe (P1000; Zubler) for 90 seconds. For the 3 experimental groups, each surface-sealant agent was applied with a soft brush in a thin and even layer in 1 direction without any air bubble formation. Twenty seconds after application, the specimens coated with materials and that their effect would not vary depending on the type of resin material.

**Clinical Implication**

Clinicians may choose the Biscover sealant agent with the Tempofit material to obtain smoother and more color-stable interim restorations and the tested sealant agents for more color-stable interim crowns.

### Table 1. Interim crown materials used

<table>
<thead>
<tr>
<th>Product</th>
<th>Code</th>
<th>Type</th>
<th>Component</th>
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<th>Shade</th>
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<tbody>
<tr>
<td>Tab 2000</td>
<td>Tab</td>
<td>Polymethyl methacrylate resin</td>
<td>Methyl methacrylate, n-butylmethacrylate</td>
<td>Kerr Corp</td>
<td>Light</td>
</tr>
<tr>
<td>Dentalon Plus</td>
<td>Dnt</td>
<td>Polymethyl methacrylate resin</td>
<td>Methacrylate, copolymer, peroxide, initiator, pigment</td>
<td>Heraeus Kulzer GmbH</td>
<td>Light</td>
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<tr>
<td>Protemp 4</td>
<td>Prt</td>
<td>Bis-acryl composite resin</td>
<td>Ethanol,2,2’-[(1-methylenebridge][4,1-phenyleneoxy)]bis-, diacetate, benzyl-phenyl-barbituric acid, silane treated silica, tert-butyl peroxy-3,5,5-trimethylhexanoate</td>
<td>3M ESPE</td>
<td>A2</td>
</tr>
<tr>
<td>Tempofit</td>
<td>Tmp</td>
<td>Bis-acryl composite resin</td>
<td>Ethoxylated bisphenol A dimethacrylate</td>
<td>Detax</td>
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### Table 2. Surface sealant materials used

<table>
<thead>
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<th>Product</th>
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<th>Component</th>
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</thead>
<tbody>
<tr>
<td>Palaseal</td>
<td>Ps</td>
<td>Methyl methacrylate, tris(2-hydroxyethyl)-isocyanurate-triacrylate, acrylatedepoxyoligomer, acrylates, acrylizedpolysiloxane</td>
<td>Heraeus Kulzer GmbH</td>
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<tr>
<td>Optiglaze</td>
<td>Og</td>
<td>Methyl methacrylate, multifunctional acrylate, silica filler, photo inhibitor</td>
<td>GC Corp</td>
</tr>
<tr>
<td>BioCover LV</td>
<td>Bc</td>
<td>Dipentaerythritolpentaacrylate, ethanol</td>
<td>Bisco Inc</td>
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Table 3. Two-way ANOVA results for comparison of Ra and ΔE00 values

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<tr>
<th>Parameter</th>
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<th>MS</th>
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<td>Interim material (A)</td>
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<td>Surface treatment (B)</td>
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<td>A x B</td>
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<td>Error</td>
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<td>0.044</td>
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ΔE00

<table>
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<td>A x B</td>
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<td>Error</td>
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<td>Total</td>
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MS, mean square; Ra, surface roughness; SS, sum of squares.
*P<0.05 indicates significant difference.

Table 4. Mean ±SD of Ra (µm) values for test groups

<table>
<thead>
<tr>
<th>Interim Crown Material</th>
<th>Control</th>
<th>Ps</th>
<th>Og</th>
<th>Bc</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMMA Tab 2.44 (0.33)bc</td>
<td>0.399 (0.256)ab</td>
<td>0.542 (0.218)ab</td>
<td>0.610 (0.382)ab</td>
<td></td>
</tr>
<tr>
<td>Dnt 2.85 (0.51)c</td>
<td>0.492 (0.190)ab</td>
<td>0.519 (0.278)ab</td>
<td>0.474 (0.140)ab</td>
<td></td>
</tr>
<tr>
<td>Bis-acryl Prt 1.82 (0.49)ab</td>
<td>0.467 (0.45)ab</td>
<td>0.457 (0.178)ab</td>
<td>0.444 (0.216)ab</td>
<td></td>
</tr>
<tr>
<td>Tmp 0.655 (0.245)bc</td>
<td>0.358 (0.123)bc</td>
<td>0.460 (0.102)bc</td>
<td>0.309 (0.192)bc</td>
<td></td>
</tr>
</tbody>
</table>

Bc, BisCover LV; Dnt, Dentalon Plus; PMMA, poly(methyl methacrylate); Prt, Protemp; Ps, Palaseal; Og, Optiglaze; Ra, surface roughness; Tab, Tab 2000; Tmp, Tempofil.

Results of Tukey post hoc comparisons are shown as superscript letters and values having same superscript letters were not significantly different (P>0.05).

Palaseal and Optiglaze were polymerized for 90 seconds in a light-polymerizing unit (Dentacolor XS; Heraeus Kulzer GmbH), whereas the specimens coated with BisCover LV were polymerized for 30 seconds with a light-emitting diode (LED) polymerization light (Elipar FreeLight 2; 3M ESPE) at a reading of 750 mW/cm². Each light-emitting diode (LED) polymerization light (Elipar BisCover LV were polymerized for 30 seconds with a Kulzer GmbH), whereas the specimens coated with Palaseal and Optiglaze were polymerized for 90 seconds Table 3.

Table 5. Mean ±SD ΔE00 values for test groups

<table>
<thead>
<tr>
<th>Interim Crown Material</th>
<th>Control</th>
<th>Ps</th>
<th>Og</th>
<th>Bc</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMMA Tab 2.44 (0.33)c</td>
<td>1.33 (0.46)c</td>
<td>1.60 (0.54)c</td>
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<tr>
<td>Dnt 2.85 (0.51)c</td>
<td>1.83 (0.45)c</td>
<td>1.79 (0.24)c</td>
<td>1.45 (0.85)c</td>
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<tr>
<td>Bis-acryl Prt 1.82 (0.49)c</td>
<td>1.46 (0.38)c</td>
<td>1.23 (0.49)c</td>
<td>1.32 (0.24)c</td>
<td></td>
</tr>
<tr>
<td>Tmp 3.61 (0.55)c</td>
<td>1.31 (0.29)c</td>
<td>1.18 (0.20)c</td>
<td>1.20 (0.12)c</td>
<td></td>
</tr>
</tbody>
</table>

Bc, BisCover LV; Dnt, Dentalon Plus; PMMA, poly(methyl methacrylate); Prt, Protemp; Ps, Palaseal; Og, Optiglaze; Ra, surface roughness; Tab, Tab 2000; Tmp, Tempofil.

Results of Tukey post hoc comparisons shown as superscript letters and values having same superscript letters were not significantly different (P>0.05).

Figure 1. Mean Ra (±SD) values of test groups. Plaque accumulation threshold levels (Ra=0.2 µm) are indicated as the X line. *Significant differences from threshold of Ra according to paired sample t test (P<0.05).

measurements were repeated 3 times for each specimen, and the means were recorded as Lo*, a0*, b0*. Specimens were embedded in wax plates to cover the unpolished surfaces. A staining solution was prepared by dissolving 7.5 g of coffee (Nescafe Classic; Nestle) in 500 mL of boiled distilled water, and the specimens were stored in this solution at 37°C in a dark environment to simulate intraoral conditions for 7 days. The staining solution was changed every 2 days throughout the test. After the staining procedure, the specimens were washed under water for 5 minutes and air-spray-dried before color measurements were made. Data were recorded as L1*, a1*, b1*. Color change values (discoloration) of the specimens were determined by using the CIEDE2000 color difference formula: $\Delta E_{00}$ color difference formula:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L}{K \Delta L_{ref}}\right)^2 + \left(\frac{\Delta C}{K \Delta C_{ref}}\right)^2 + \left(\frac{\Delta H}{K \Delta H_{ref}}\right)^2 + \frac{R_T}{K} \left(\frac{\Delta C}{K \Delta C_{ref}}\right) \left(\frac{\Delta H}{K \Delta H_{ref}}\right)}$$

where ΔL’, ΔC’, and ΔH’ are the differences in lightness, chroma, and hue for a pair of specimens in CIEDE2000 and R_T is the rotation factor that accounts for the
interaction between chroma and hue differences in the blue region. $S_L$, $S_C$, $S_H$ adjust the total color difference for variations in the location of the color difference pair in the $L'$, $a'$, $b'$ coordinates and the parametric factors. $K_L$, $K_C$ and $K_H$ are the terms for the experimental conditions. In the present study, the parametric factors of the CIEDE2000 color difference formula were set to 1. Also, the perceptibility threshold was set at $D_{E00}/C_{20} \leq 1.30$ units, and the clinical acceptability threshold was set at $D_{E00}/C_{20} \leq 2.25$ units.

The data were statistically analyzed, and computations were performed using statistical software (SPSS version 17.0; SPSS Inc). The Levene test of homogeneity was used to evaluate the distribution of the variables. $R_a$ and $\Delta E_{00}$ results were analyzed separately with the 2-way ANOVA test to evaluate the effects of interim material type, surface treatment techniques, and their interactions. Mean $R_a$ and $\Delta E_{00}$ values were then compared with the Tukey HSD test. A comparison of mean $R_a$ values with plaque accumulation threshold levels ($R_a=0.2$) and also of mean $\Delta E_{00}$ values with clinically acceptability ($\Delta E_{00} \leq 2.25$) and perceptibility threshold ($\Delta E_{00} \leq 1.30$) levels were analyzed using the paired sample $t$ test ($\alpha=.05$).

**RESULTS**

According to the 2-way ANOVA of both the $R_a$ and $\Delta E_{00}$ results, the effects of the interim material and surface treatment technique were statistically significant. Their interaction was significant only for color stability ($P<.05$) (Table 3). Mean ±SD $R_a$ and $\Delta E_{00}$ values for the interim material/surface treatment technique combinations are shown in Tables 4 and 5.

The $R_a$ values for all groups (0.309 to 0.796 $\mu$m) were significantly higher than the plaque accumulation threshold level (0.20 $\mu$m), except for Tmp_Bc ($P=.089$; $P<.05$) (Fig. 1). For all groups, even though interim materials coupled with a surface sealant agent had lower $R_a$ values than conventionally polished materials, statistically significant differences were observed only between the Tmp control and Tmp_Bc ($P=.026$). No significant differences were found among the other groups ($P>.05$). The highest $R_a$ value was observed in the Dnt control...
group (0.796 μm), and the lowest Ra value was determined for the Tmp_Bc group (0.309 μm) (Fig. 5). SEM images of the Tab, Dnt, Prt, and Tmp interim material surfaces after the surface treatments are shown in Figures 2-5.

Mean color differences (ΔE<sub>00</sub>) for the conventionally polished Tab, Dnt, and Tmp interim material groups were above the clinical acceptability threshold level (ΔE<sub>00</sub> > 2.25). However, only the ΔE<sub>00</sub> values of Dnt_C (P<.002) and Tmp_C groups were significantly different than the acceptability threshold level according to the paired sample t test results (P<.001). The ΔE<sub>00</sub> values of the Prt_Og, Tmp_Bc and Tmp_Og groups were below the perceptibility threshold (ΔE<sub>00</sub>≤1.30); however, according to the paired sample t test results, the difference was statistically significant only in the Tmp_Bc test group (P=.023). All other ΔE<sub>00</sub> values were within clinically acceptable limits (1.30≤ΔE<sub>00</sub>≤2.25), but still in the range of visual perceptibility. Although the highest ΔE<sub>00</sub> was observed in the Tmp_C group (3.61), the lowest was seen in the Tmp_Bc group (1.20) (Fig. 6).

When conventionally polished groups were compared, the highest ΔE<sub>00</sub> values were obtained for Tmp (P<.001) and the lowest for the Prt group, which was significantly lower than those of Tmp (P<.001) and Dnt (P<.001). When the difference between the ΔE<sub>00</sub> values of the control group and surface sealant agent groups were compared, the greatest and most significant differences were observed for the Tmp, Dnt, and Tab groups (P<.05). No statistically significant difference was found among the surface sealant agent groups for all interim materials (P>.05).

**DISCUSSION**

The null hypothesis was rejected. Although the results of the surface treatment techniques and interim material type were significant on both surface roughness and color stability, their interaction had no effect on surface roughness. In the present study, Ra values ranged between 0.309 and 0.796 μm. Although these values were above the threshold Ra of 0.2 μm that Bollen et al<sup>23</sup> indicated, they were below the 10-μm limit of clinical
undetectability identified by Kaplan et al. This situation shows that the single-phase surface treatment procedures used in the current study could be suitable for short-term interim restorations as previously stated by Borchers et al. Similar to the study findings of Ayuso-Montero et al., conventionally polished PMMA resins showed higher surface roughness values compared with those of bis-acryl composite resins. In contrast, several studies noted the smoother surfaces of methacrylate resins compared with those of bis-acryl composite resins. Regardless of the surface polishing technique used, the inherent chemistry of the material, the initiator, the resin matrix composition, and the existence of filler particles, as well as their size and distribution, affect polishability and smoothness.

Sealant agents are recommended for improving the optimal properties and especially the surface smoothness of restorations by filling by capillary action the microfissures and microdefects that form after the finishing/polishing procedures. However, the sealant agents can lead to problems such as low resistance to abrasion, weak retention to the underlying material, and poor surface quality resulting from uneven spreading that may depend on high viscosity. In the present study, even though not statistically significant, the use of surface-sealant agents resulted in lower Ra values for all interim resin material groups compared with the conventional polishing method. For the Tab and Dnt resin groups, this may have occurred because the sealant agents decreased the surface roughness by increasing the molecular weight of the methacrylate components, as previously stated by Borchers et al.

The preparation method of the interim crown material, automixed or hand-mixed, affects surface porosities and defects. Hence, the surface roughness, water sorption, and accordingly the color stability may be affected by trapped air or unreacted monomer. SEM analysis in the present study revealed greater porosity and air bubbles on the conventionally polished Dnt specimen surface, which was prepared by hand mixing (Fig. 3). This image was similar to the second type of pore formation.
described by Kuhar and Funduk. Air may have been incorporated at a later stage of mixing, such as after the monomer had completely perfused the acrylic resin powder. SEM analysis showed that for all the resin groups, the application of the surface sealant agent reduced the surface roughness. The specimens which represented the highest and the lowest Ra values had SEM images consistent with the surface roughness measurement results.

In the current study, coffee was used because of its high staining potential. Discoloration with coffee may have occurred through the absorption and adsorption of polar colorants into/onto the organic phase of resin materials. Depending on the composition of the interim material and the type and degree of polymerization, staining may vary. The chemical properties of materials such as the size and distribution of the poly-methyl methacrylate particles, stability of pigments, polarity of monomers, effectiveness of the initiator system, filler content, and cross-linking amount are important factors in the degree of polymerization, water sorption, and color stability. Most bis-acryl polymers are more polar than PMMA because they have a greater affinity to water and other polar liquids. In the present study, the differences regarding filler content, amount of cross-linking, and hence water sorption were the unknown parameters that may have affected the color results of the PMMA and bis-acryl resin material test groups. Also, the presence of porosity and more dense filler particle content seen in the SEM images of the Dnt and Tmp control groups may have caused higher DE0 values. Several studies have reported that larger filler particle size and hence the decreased amount of filler content results in greater Ra values. Accordingly, an increase in the size of filler particles would result in surface irregularities, causing a difference in color. The difference between the DE0 values of the Prt and Tmp control groups can be attributed to the variation in the amount, type, and size of filler particles and may be responsible for the differences observed in the SEM images (Figs. 3, 4). Also, early discoloration of materials is known to be associated with finishing, polishing and, coating procedures and therefore with surface roughness.

Figure 5. Scanning electron micrograph analysis (×1000 magnification). A, conventionally polished (note rougher surface). B, Palaseal. C, Optiglaze. D, BisCover LV with Tempofit interim crown material.
the surface roughness and color difference compared with the control groups. The greatest color change values were obtained in the conventionally polished specimens for all resin groups. Similar to the study findings of Doray et al.10 the application of surface sealant on both bis-acryl resin groups generally resulted in better $\Delta E_{\text{op}}$ by reducing the values below the perceptible threshold (in Prt_Og and Tmp_Og groups) ($\Delta E_{\text{op}} < 1.30$). The use of the sealant agents tested in the current study led to similar values for color differences for each resin group.

This in vitro study has limitations. The Vita Easy Shade has a limited color library of LAB values, and these results should be corroborated with advanced color measuring instruments. Occlusal contacts, nutritional habits, tooth brushing, mouth rinsing, saliva, and opposing restorations should be considered in future investigations. Also, further research is needed to evaluate the long-term performance of the sealant agents on candida or bacterial adhesion, wear resistance, and optical properties compared with different laboratory and chairside polishing techniques.

**CONCLUSIONS**

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

1. All groups had a surface roughness higher than the plaque accumulation threshold (0.20 $\mu$m).
2. The use of the Discover LV surface sealant agent on Tempofit significantly decreased the surface roughness compared with the conventionally polished Tempofit specimens.
3. Conventionally tested specimen groups (except Prt group) exhibited a clinically unacceptable color change after staining ($\Delta E_{\text{op}}>2.25$).
4. For all interim resin groups, the application of surface sealant improved color stability and provided clinically acceptable color changes after staining.

**REFERENCES**


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