Influence of surface sealant agents on the surface roughness and color stability of artificial teeth

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Surface roughness and surface free energy are important predictors of the performance of dental restorative materials.1-6 When the external surface of a dental restoration is rough, more plaque forms,7 promoting tooth loss due to caries or periodontal disease as well as denture stomatitis.1-4,6,7 In recent studies, a threshold level of surface roughness (Ra=0.2 μm) has been indicated for plaque accumulation. Although no further reduction in plaque accumulation was expected for the smooth surfaces below this borderline level, higher surface roughness resulted in a simultaneous increase in plaque accumulation.4,8 Furthermore, dental restorations with rough surfaces are more prone to staining and discoloration, leading to reduced esthetics and acceptability of the restoration.2,7

Denture teeth are commonly used in complete and partial dental prostheses.5,9-13 When the denture teeth are placed in direct contact with natural teeth or oral soft tissues, extensive plaque formation may contribute to caries or periodontal disease adjacent to the denture.5 Plaque formation and discoloration can be reduced by polishing the denture teeth,7,4 which has conventionally been done in the dental laboratory with aluminum oxide pastes or liquids.4,14 Various chairside polishing kits and surface sealants are available if the prosthesis cannot be returned to the dental laboratory after grinding.

ABSTRACT

Statement of problem. Although various surface sealant agents are available and recommended for chairside polishing procedures, their effect on the surface roughness and color stability of denture teeth is not clear.

Purpose. The purpose of this in vitro study was to evaluate the effect of sealant agents on the surface roughness and color stability of various denture tooth materials.

Material and methods. Eighty disk-shaped specimens were prepared for each type of denture tooth material (SR Vivodent, PMMA; Vitapan, reinforced-PMMA; SR Phonares II, composite resin). The specimens were assigned to 4 groups according to the surface treatment used (n=20): surface sealant agents (Palaseal; Heraeus Kulzer GmbH, Optiglaze; GC Corp Biscove; Bisco Inc) and a conventional laboratory polishing technique (control group). A thermal cycling procedure was applied for half of the specimens (n=10). The surface roughness (Ra) values of thermocycled and nonthermocycled specimens were measured with a profilometer. The CIELab color parameters of both thermocycled and nonthermocycled specimens were measured with a spectrophotometer at baseline and after 7-day storage in a coffee solution. The color differences were calculated from the CIEDE2000 (ΔE00) formula. Data were statistically analyzed with 3-way ANOVA and the Tukey HSD test (α=.05).

Results. The type of tooth material, surface treatment technique, and their interactions were significant for Ra values, and each variable and their interactions were also significant for ΔE00 values (P<.05). Thermal cycling had a significant effect only on ΔE00 values (P<.05).

Conclusions. Palaseal and Optiglaze sealant agents provided smoother and more color-stable denture tooth surfaces than the conventional polishing technique. The use of the Biscove agent with SR Vivodent and Phonares II teeth increased the Ra values. The color of conventionally polished SR Vivodent and Phonares II teeth changed more with thermal cycling. (J Prosthet Dent 2015;114:130-137)
The application of surface sealant agents onto the resin restoration is intended to fill in surface defects, increase wear resistance, and provide better stain resistance. However, their long-term performance has not been fully reported. The purpose of this study was to evaluate the effect of sealant agents and thermal cycling on the surface roughness and color stability of different denture teeth. The first null hypothesis was that the application of different sealant agents would not affect the surface roughness and color stability of acrylic and composite resin teeth. The second null hypothesis was that the effect of sealant agents would not vary depending on the type of teeth. The third null hypothesis was that the effect of sealant agents would not vary depending on thermal cycling.

MATERIAL AND METHODS

A total of 240 standardized labial sections were cut from the labial surfaces of 3 different commercially available denture teeth: an unfilled PMMA (SR Vivudent PE, or SrVi), a microfiller reinforced PMMA (Vitapan, or Vita), and a nanofilled composite (SR Phonaires II, or SrPh). Disk-shaped labial sections (6×2 mm) were prepared from the largest available A2 shade central incisors with minimal labial surface texture with a standardized template and trephine bur (Hager & Meisinger GmbH). Before the polishing procedures, the specimens were ground-finished with 400-grit silicon carbide abrasive paper on a machine (Phoenix Beta; Buehler) under water cooling. Twenty specimens for each denture tooth group were polished with a conventional laboratory polishing technique (control group) and the other 60 specimens were divided and coated with 3 different surface sealant techniques (control group) and the other 60 specimens were immersed in the coffee solution in a stainless steel container and stored at 37°C for 7 days to simulate intraoral conditions. After the staining procedure, each specimen was washed under water and air-dried, and color measurements were made. Data were recorded as L1*, a1*, b1*.

The color change values of TC and NT denture teeth after different surface treatments were calculated with the following CIEDE2000 formula:

$$\Delta E_{00} = \sqrt{\left( \Delta L^* \right)^2 + \left( \Delta a^* \right)^2 + \left( \Delta b^* \right)^2 + \text{RT} \left( \Delta C^* \right) \left( \Delta H^* \right)}$$

where \( \Delta L^*, \Delta C^*, \text{ and } \Delta H^* \) are the differences in lightness, chroma, and hue for a pair of specimens in \( \Delta E_{00} \), and where RT is a function that accounts for the interaction between chroma and hue differences in the blue

Clinical Implications

Clinicians may use a surface sealant coupling technique to achieve smooth and color-stable denture tooth surfaces after chairside grinding procedures.
The Ra and ∆E₀₀ data were statistically analyzed. First, the Levene test of homogeneity was used to evaluate the normal distribution of the variables. Secondly, the Ra and ∆E₀₀ results were separately analyzed by 3-way ANOVA to evaluate the effects of denture tooth type, surface treatment techniques, thermal cycling, and their interactions. Finally, the mean Ra and ∆E₀₀ values were also separately compared by using the Tukey HSD multiple comparison test. Significance was evaluated at P<.05 for all tests. All the computational work was performed with statistical software (SPSS v17.0; SPSS Inc).

RESULTS

According to the 3-way ANOVA, the type of denture teeth, surface treatment technique, and their interactions were significant for Ra values (Table 2) (P<.05). The mean Ra values and standard deviations for denture tooth/surface treatment combinations for the NT and TC groups are listed in Table 3 (Fig. 1).

Only the SrVi_Bc and BC (SrPh_Bc) specimens had higher Ra values (0.278 to 0.355 μm) than the plaque accumulation threshold level (0.20 μm). While the highest Ra value was determined for the TC_SrPh_Bc group (0.355 μm), the lowest Ra value was determined for the NT_SrPh_Ps group (0.043 μm). The BC sealant agent coupling significantly increased the Ra of SrVi and SrPh denture teeth compared with the other sealant agents and control groups (P<.05). However, Vita denture tooth groups had decreased Ra values when the BC sealant agent coupling was used. The coupling of each denture tooth with Ps and Og agents resulted in smoother surfaces than with conventional polishing; however, no statistically significant differences were found among them. SEM images of SrVi, Vita, and SrPh denture teeth surfaces after surface treatments are shown in...
Figs. 1-4. The SEM images show that the sealant-coupled specimens had smoother surfaces than the control groups. Additionally, topographical changes, including micropores, cavities (Figs. 2D, 4D), and microcracks (Fig. 2D), were observed for Bc agent-coupled SrVi and SrPh specimens. An irregular surface was also observed for Vita_C (Fig. 3A).

The 3-way ANOVA results showed that each variable and their interactions (except the interaction between tooth type and surface treatment) were significant for color difference values (Table 2) (*P<.05). The mean ΔE00 values and standard deviations for denture tooth/surface treatment combinations for the NT and TC groups are listed in Table 4. The mean color differences for each control group (NT SrVi_Og, SrVi_Bc, and SrPh_Bc tooth groups; TC Vita_Ps, SrPh_Ps, and SrPh_Og tooth groups) were above the acceptability threshold level (ΔE00 ≤ 2.25). Even though all other ΔE00 values were within the clinically acceptable limits (1.30 < ΔE00 ≤ 2.25), they were in the range of visual perceptibility. While the highest ΔE00 was observed for the TC_SrVi_C group (3.46), the lowest was observed for the TC_Vita_Og group (1.59). In general, conventional polishing produced the highest ΔE00 for each tooth group. A statistically significant difference was found between the conventionally polished and other surface treatment groups for TC_SrPh, NT_Vita (except Vita_Bc), and TC_Vita (except TC_Vita_Ps) teeth (*P<.05). Sealant agent coupling techniques reduced the ΔE00 values.

Thermal cycling application significantly increased the ΔE00 values of SrVi and SrPh tooth groups (*P<.05). When denture tooth types were compared for each surface treatment and thermal cycling procedure, the highest ΔE00 values were obtained for the SrVi tooth groups. However, Vita teeth were the most stain-resistant group. A statistically significant difference was found between the thermocycled Og/Bc sealant agent coupled SrVi and Vita groups (*P<.05). Regression analysis found the coefficient of correlation between Ra and ΔE00 values to be statistically significant (*P=.011, r²=.165) (Fig. 5).

**DISCUSSION**

All null hypotheses were rejected, because surface treatment techniques and tooth type significantly affected both surface roughness and color stability, and thermal cycling had a significant effect on color stability (*P<.01). Significant differences were found in Ra and ΔE00 values among the groups (*P<.05). Thermal cycling had no effect on surface roughness.

All teeth coated with Ps and Og had smoother surfaces than those in conventionally polished groups. Similarly, previous studies have found that surface-penetrating sealant or glaze materials result in significantly lower Ra values than conventional polishing techniques (aluminum oxide abrasive disks or silicone wheel systems). However, in this study, when Bc was used, only the surfaces of Vita teeth were smoother than the control group. The Bc sealant agent caused significantly rougher surfaces for SrVi and SrPh tooth groups than for their control groups. In addition, the Ra values were higher than the 0.2 μm threshold level. This unexpected result may be explained by surface irregularities caused by the removal of unpolymerized or nonadhered...
A film of incompletely polymerized layer occurs on the surface of composite resin materials when they are contact with oxygen in the air. Because intraoral factors may easily remove this layer, surface defects such as microcracks may occur. Additionally, the formation of air bubbles in the sealant material during its application by brushing may also cause surface irregularities and increase the Ra values. Microcracks and cavities were observed in the SEM images of SrVi_Bc and SrPh_Bc specimens (Figs. 2D, 4D).

The mechanical properties and surface roughness of resin materials depend on the filler particle size, hardness, and percentage content. Silicon dioxide, glass, and ceramic are the preferred inorganic filler materials. The polishing of filled resins causes a higher fraction of these inorganic components in the surface layer and thus increases the roughness and free energy. A similar study found that unfilled resins tended to decrease surface roughness with the increasing molecular weight of methacrylate components. In another study, although low bacterial adhesion and fluorescence values were found for PMMA resin teeth, the highest Ra values and the highest adhesion of bacteria were observed for filler-supplemented resin teeth. In agreement with these previously reported results, the Ra values of SrVi_C (unfilled PMMA) teeth were lower than those of Vita_C (micro-filler reinforced polyacrylic resin) and SrPh_C (nano-filled composite resin) tooth groups. The SEM images also showed an irregular surface texture of Vita_C specimens, perhaps because of the fraction of the inorganic filler components (Fig. 3A).

The discoloration of resin-based materials is a complex phenomenon and is associated with several mechanisms, including surface roughness and chemical and physical interactions. Although obtaining a precise relationship between surface roughness and staining is not usually possible, surface roughness has been shown to be the main reason for the adsorption of stains. The adsorption and absorption of a colorant onto/into the organic phase of resin materials and the high surface reactivity of poorly polymerized surfaces have also been blamed for staining. In this study, the color changes for specimens treated with conventional polishing technique were not only higher than the sealant coupling techniques but also above the acceptable threshold, regardless of denture tooth type or thermal cycling ($\Delta E_{00}=2.54-3.46$). Although each sealant agent coupling technique reduced the staining potential of denture teeth, the color change values of SrVi_Bc and SrPh_Bc were above the acceptable threshold ($\Delta E_{00}=2.31-2.81$). Reducing surface irregularities and
defects and enhancing surface smoothness may account for the sealant agent’s superiority in providing improved resistance to stain. The higher ΔE00 values for SrVi_Bc and SrPh_Bc teeth were also correlated with higher Rₐ values. Conversely, a previous study indicated that the discoloration of coating resins depended on the resin composition and that leaving incomplete polymer networks and matrix film on the finished surface of sealant-coated specimens may make them more open and accessible to colorants. As a result, the absorption of colorants and penetration into the matrix of coating material caused internal staining. The different results obtained for the sealant agents evaluated in this study could also be attributed to the intrinsic factors of these materials. In another study, the effect of resin surface sealers on the staining resistance of an interim material was evaluated. The authors concluded that the polymerization duration and content of the sealant material affected the staining resistance and that using methacrylate- or dimethacrylate-containing glaze materials improved resistance more than those containing ethoxylatedbisphenol-A dimethacrylate. The results of the present study were similar to this finding. The dipentaerythritolpentaacrylate-containing Bc sealant agent was less stain resistant than the methacrylate- or PMMA-containing Ps and Og agents. In the present study, while the Ps and Og sealant agents were light-polymerized for 90 seconds, the Bc agent was light-polymerized for only 30 seconds. The shorter polymerization time might have affected the stain resistance of Bc, which was also mentioned in a previous study.

Although the color change of sealant agent/denture tooth specimens was substantially associated with the sealant agent’s intrinsic and/or extrinsic staining factors, conventionally polished specimens were affected by the chemical and physical factors of the teeth themselves. In the present study, the color change values of conventionally polished teeth were close to each other. However, significant increases were observed for TC SrVi and SrPh teeth compared with NT groups. This result was consistent with the results reported in a previous study, in which the color of denture teeth was affected by thermal cycling. In addition, the SrVi teeth exhibited the greatest change in color when compared with different brands of denture teeth. Another study showed that the color change value of SrVi teeth in coffee solution was significantly greater than that of the Vita teeth and that discoloration ratios increased with the immersion period. The color change of resin materials after thermal cycling may be associated with the absorption and adsorption of the discolorant. Increasing the hydrophobic content of denture teeth may
reduce the susceptibility to water sorption and staining.\textsuperscript{10-12} In the present study, the lower color change values for TC_Vita teeth than for SrVi teeth may be explained by the higher degree of hydrophobic cross-linking and filler content, which might have caused less water sorption. The effects of thermal cycling and water immersion on the discoloration of composite resins were not only associated with the oxidation of amine accelerators but also the alteration of the organic matrix and matrix-filler interface.\textsuperscript{10,13,16,17} The potential swelling of the composite resin matrix by water uptake should increase the staining tendency and may also explain the high color change values for the TC_SrPh teeth evaluated. A previous study indicated that the frame of the filler content may also affect the discoloration results. Using silanized filler content might reduce the formation of microgaps and microfractures.

### Table 4

<table>
<thead>
<tr>
<th>Denture Tooth</th>
<th>Surface Treatment</th>
<th>Mean (SD)</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR Vivodent</td>
<td>Control</td>
<td>2.69 (0.65)</td>
<td>3.46 (0.30)</td>
</tr>
<tr>
<td></td>
<td>Palaseal</td>
<td>1.91 (0.54)</td>
<td>2.65 (0.37)</td>
</tr>
<tr>
<td></td>
<td>Optiglaze</td>
<td>2.46 (0.42)</td>
<td>2.65 (0.50)</td>
</tr>
<tr>
<td></td>
<td>Biscover</td>
<td>2.42 (0.31)</td>
<td>2.81 (0.39)</td>
</tr>
<tr>
<td>Vitapan</td>
<td>Control</td>
<td>2.75 (0.67)</td>
<td>2.86 (0.97)</td>
</tr>
<tr>
<td></td>
<td>Palaseal</td>
<td>1.79 (0.56)</td>
<td>2.31 (0.84)</td>
</tr>
<tr>
<td></td>
<td>Optiglaze</td>
<td>1.83 (0.53)</td>
<td>1.59 (0.54)</td>
</tr>
<tr>
<td></td>
<td>Biscover</td>
<td>1.93 (0.93)</td>
<td>1.92 (0.31)</td>
</tr>
<tr>
<td>SR Phonares</td>
<td>Control</td>
<td>2.54 (0.23)</td>
<td>3.37 (0.35)</td>
</tr>
<tr>
<td></td>
<td>Palaseal</td>
<td>1.89 (0.20)</td>
<td>2.33 (0.24)</td>
</tr>
<tr>
<td></td>
<td>Optiglaze</td>
<td>2.03 (0.29)</td>
<td>2.34 (0.43)</td>
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<tr>
<td></td>
<td>Biscover</td>
<td>2.31 (0.18)</td>
<td>2.39 (0.50)</td>
</tr>
</tbody>
</table>

Results of Tukey HSD post hoc comparisons are shown as superscripts, and values having same letters are not significantly different (P > .05). Uppercase letters indicate differences between NT and TC groups and lowercase letters indicate differences between denture tooth/surface treatment combinations.

### Figure 4

Scanning electron micrograph analysis (×2500) of A, SrPh_C (note rougher surface compared with test groups); B, SrPh_Ps; C, SrPh_Og; and D, SrPh_Bc (note micropore/cavity on surface).

### Figure 5

Correlation plot for $R_a$ ($\mu$m) and $\Delta E_{00}$ values.
among the resin matrix-filler interfaces and thus decrease water uptake and staining probabilities. Several studies have reported that the resin matrix type played a major role in the color stability of the composite resins and that greater discoloration was recorded for the composite resins with triethylene glycol dimethacrylate (TEGDMA) than for those with diglycidyl ether methacrylate (bis-GMA) or urethane dimethacrylate (UDMA).16,17 In the present study, although the SrPh composite resin teeth have UDMA resin matrix and silanized Si-Ox filler composition, the effect of thermal cycling might have damaged the matrix-filler connection and thus increased the staining potential.

This in vitro study has some limitations. Only 1 brand of denture teeth was evaluated for each PMMA, reinforced-PMMA, and composite resin tooth group. The long-term performance of sealant agents on candida or bacterial adhesion, wear resistance, and optical properties may also be investigated and compared with different laboratory and chairsde polishing techniques. In the present study, the time of the thermal cycling procedure was limited and only 1 type of staining solution was used to simulate the intraoral conditions. However, many other factors such as occlusal relations, nutritional habits, toothbrushing, mouth rinsing, and saliva should be taken into consideration. The conclusions of this study should be verified with long-term clinical studies.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

1. The type of denture tooth material and surface treatment technique were significant for both $R_a$ and $\Delta E_{00}$ values, but thermal cycling was only significant for $\Delta E_{00}$ values.
2. The use of surface sealant agents decreased the $R_a$ and $\Delta E_{00}$ values except for the Discover sealant agent, which caused a significantly rougher surface for SR Vivodent and Phonares II teeth than for the teeth in the conventionally polished groups.
3. Conventionally polished teeth showed the highest color changes, which were clinically unacceptable ($\Delta E_{00}$ > 2.25). The color change of the conventionally polished SR Vivodent and Phonares II teeth significantly increased with thermal cycling.
4. Color changes after the use of some sealant agents were visually perceptible but clinically acceptable (1.30 $< \Delta E_{00}$ $\leq$ 2.25) for different tooth groups.

REFERENCES