Basic evaluation on physical properties of experimental fluorinated soft lining materials

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The purpose of the present study was to compare the properties required for the clinical application of soft lining materials containing a fluorinated monomer versus that of conventional materials in an effort to develop a new soft lining material with long-term stable viscoelastic properties. Four soft lining materials were examined. Two experimental materials containing dodecafluoroheptyl methacrylate (SR12F) or tridecafluoroctyl methacrylate (SR13F) were prepared. Two commercial soft lining materials, one acrylic-based and one silicone rubber-based, were selected as reference materials. Shore A hardness, viscoelastic properties, water sorption, solubility, and staining resistance were evaluated. The Shore A hardness and the displacements were analyzed with two-way analysis of variance (ANOVA) and Tukey’s HSD test. The water sorption, the solubility and the color change were analyzed with one-way ANOVA and Tukey’s HSD test. The significance level was set at 0.05. SR12F and SR13F showed greater viscous flow, low water sorption, low solubility, and good staining resistance compared to the commercial products. The results indicate that the soft lining materials containing fluorinated monomers might have a potentially long-term stable viscoelastic behavior.

Keywords: Soft lining materials, Fluorinated monomers, Viscoelastic behavior

INTRODUCTION

As society becomes increasingly elderly, the number of patients with difficulties in undergoing complete denture treatment, including a highly absorbed alveolar ridge, is increasing. In the case of an extremely resorbed residual ridge, the overlying mucosa decreases in thickness according to the resorption1). When the shock-absorbing effect of the mucosa is diminished, masticatory impact forces are directly transmitted to the underlying tissue. As a result, the burden on the residual ridge increases. In addition, irritation or soreness spreads on the basal seat, due to the pinching of the thin mucosa between the hard denture base and the bone during mastication. In such a case, it is necessary to line the inner surface of the denture base with a soft material similar to the mucosa in order to compensate for the lost thickness and viscoelastic behavior of the mucosa. The pain is relieved by reducing the impact force during mastication and dispersing the force widely over the alveolar ridge to give a cushioning effect. Therefore, the clinical performance of soft lining materials is considered to relate with the viscoelastic properties2). The application of a soft lining material to the mandibular denture can also increase the patient’s masticatory performance and biting force, thereby improving the chewing rhythm3). Presently, materials made of acrylic and silicone rubber are mainly used for a soft lining material4,5). The acrylic-based soft lining materials strongly adhere to the acrylic resin denture base, but the added plasticizer will gradually diffuse onto the surface of the resin. Furthermore, this plasticizer can be leached out by the saliva, resulting in the gradual hardening of the materials6). In addition, there is a problem of bacterial contamination, which may be due to the roughness of the surface or water sorption of the materials7). Furthermore, the elution of residual monomers may produce soft tissue reactions such as redness and swelling of the oral mucosa and pain8). The degree of tissue irritation depends on the amount of eluted residual monomer9). On the other hand, silicone rubber-based soft lining materials are chemically stable and their elasticity can be maintained. However, it is difficult to adhere the material directly to acrylic resin, thus making an adhesive necessary to obtain sufficient bond strength10,11). In addition, the silicone rubber-based soft lining materials enhance the growth of fungi such as Candida albicans on the presence of saliva12). The materials are required to be minimally contaminated from the viewpoint of oral hygiene13,14). Fluorocarbon polymers have been applied to the dental field because of their excellent characteristics including chemical stability, water and oil repellency, and contamination resistance15,16). A fluoropolymer soft lining material (Kurepeet Dough, KPD; Kurecha Co., Tokyo, Japan), that was developed by Hayakawa et al., exhibited extremely low water sorption and excellent adhesion to acrylic resins17). Moreover, a dough-type fluoropolymer soft lining material (Kurepeet Dough, KPD; Kurecha Co.) was developed to improve usability and softness without sacrificing the excellent physical properties of KP18). However, these materials are not available at present, because the carbon tetrachloride used in the
production process was banned by the Montreal Protocol. Therefore, development of soft lining material without the use of carbon tetrachloride was initiated. In the previous basic study on this development, the influences of fluorinated monomers on physical properties and contamination resistance were assessed and the use of monomers with a large number of fluorine atoms in one molecule was suggested to be useful for soft lining materials. However, it was necessary to elucidate other properties required for clinical applications, such as viscoelastic behavior, to successfully use a fluorinated monomer as a soft lining material.

In this study, two experimental fluorinated soft lining materials were prepared. These materials contained currently-available monomers with a large number of fluorine atoms in one molecule: dodecafluoroheptyl methacrylate (12F) and tridecafluorooctyl methacrylate (13F). The purpose of the present study was to compare the properties required for clinical application of soft lining materials containing a fluorinated monomer versus that of conventional materials in an effort to develop a new soft lining material with long-term stable viscoelastic properties.

MATERRIALS AND METHODS

Materials and preparation of test specimens

Four soft lining materials were examined. Two experimental materials containing 12F or 13F were prepared and were named SR12F and SR13F, respectively. The constituents of these materials are listed in Table 1. The two commercial soft lining materials used were an acrylic-based soft lining material (VertexSoft clear, VS; Vertex Dental B.V, Zeist, Netherlands) and a silicone rubber-based soft lining material (Molloplast-B, MB; Detax, Ettlingen, Germany) (Table 1).

Cylinder-shaped and disc-shaped stainless-steel molds (diameter: 10 mm; height: 10 mm, diameter: 20 mm; thickness: 1 mm) were placed on a stainless-steel plate. Each soft lining material was injected into the molds. After injection, the other open side was pressed tightly with another stainless-steel plate and the mold was placed into a boiling bath (AQUA MARATHON, Code | Manufacturer | Composition
--- | --- | ---
SR12F | Experimental | Vinylidene fluoride/hexafluoro propylene copolymer (55%) Methoxy diethylene glycol methacrylate (12%) Polyethyl methacrylate (1%) Fumed silica (20%) Dodecafluoroheptyl methacrylate (12%)
SR13F | Experimental | Vinylidene fluoride/hexafluoro propylene copolymer (55%) Methoxy diethylene glycol methacrylate (12%) Polyethyl methacrylate (1%) Fumed silica (20%) Tridecafluorooctyl methacrylate (12%)
VS | Vertex Dental B.V., Zeist, Netherlands | Polyethyl methacrylate Ethyl methacrylate
MB | Detax, Ettlingen, Germany | α-ω-dihydroxy end blocked polydimethyl siloxane

Table 2 | Processing conditions for each material
--- | ---
Code | Processing condition
SR12F | Mooring from 20 to 100°C (temperature raised within 60 min), and 30 min at 100°C
SR13F | Mooring from 20 to 100°C (temperature raised within 60 min), and 30 min at 100°C
VS | 3 hours at 70°C, followed by 30 min at 100°C
MB | 2 hours at 100°C
Dentrochemical, Tokyo, Japan) for polymerization. The polymerization process conditions for each material are summarized in Table 2. After polymerization, the specimens were removed from the mold and trimmed with a sharp blade. The 25 specimens comprised 10 cylinder-shaped specimens of each material for Shore A hardness test and creep test and 15 disc-shaped specimens of each material for the water sorption and solubility test and staining resistance test.

**Hardness**

Shore A hardness was determined using a durometer (Model DD2-A, Kobunshi Keiki Co., Kyoto, Japan) according to ISO 10139-2:2009. After immersion of the specimens in deionized water at 37°C for 24 hours and 1 week, the specimens were subjected to the test. The values at 5 seconds after loading were recorded.

**Viscoelastic properties**

The viscoelastic properties were measured by a creep test using a creepmeter (Rheoner RE3305, Yamaden, Tokyo, Japan). A 3-mm ball-shaped probe was used to eliminate the effect of deformation during measurements. The creep test was performed at a cross-head speed of 1 mm/second until the load reached 1.96 N (200 gf), and the load was maintained for 60 seconds. Changes in the load and displacement of the probe were recorded to a personal computer and the viscoelastic parameter, instantaneous elastic displacement, delayed elastic displacement and viscous flow were calculated using the Voigt four-element model. The Shore A hardness and the displacements were determined with a spectro-differential colorimeter (Minolta CR-13, Konica Minolta Co., Tokyo, Japan). Prior to measurements, these specimens were placed inside an ultrasonic bath (VC-1, AS ONE, Osaka, Japan) for 5 minutes. A white background was used during measurements, and the values were determined three times for each specimen to obtain the L* value (brightness), a* value (red-green proportion) and b* value (yellow-blue proportion). The color change (ΔE) was determined as:

\[ \Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \]

where, \( \Delta L^* \), \( \Delta a^* \) and \( \Delta b^* \) are differences in the respective L*, a* and b* values before and after staining solution immersion.

**Staining resistance**

Staining resistance was evaluated as the color differences before and after staining solution immersion for 1 week at 37°C. The staining solutions used were 2% coffee (NESCAFE Excella, Nestle Japan Co., Hyogo, Japan) and 0.1% \( \beta \)-carotene/olive oil (07312-94, Nacalai Tesque Co., Kyoto, Japan/BOSCO, The Nisshin OilliO Group Co., Tokyo, Japan). According to the CIE regulations, \( L^*a^*b^* \) values before and after immersion were determined with a spectrophotometer (Minolta CR-13, Konica Minolta Co., Tokyo, Japan). Prior to measurements, these specimens were placed inside an ultrasonic bath (VC-1, AS ONE, Osaka, Japan) with a neutral detergent (Charmy Green, Lion Co., Tokyo, Japan) for 5 minutes. A white background was used during measurements, and the values were determined three times for each specimen to obtain the \( L^* \) value (brightness), \( a^* \) value (red-green proportion) and \( b^* \) value (yellow-blue proportion). The color change (ΔE) was determined as:

\[ \Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \]

where, \( \Delta L^* \), \( \Delta a^* \) and \( \Delta b^* \) are differences in the respective L*, a* and b* values before and after staining solution immersion.

**Statistical analysis**

The Shore A hardness and the displacements were analyzed with two-way analysis of variance (ANOVA) and Tukey’s HSD test using statistical software program (JMP8, SAS, Tokyo, Japan). The water sorption, the solubility and the color change were analyzed with one-way ANOVA and Tukey’s HSD test. The significance level was set at 0.05.
RESULTS

Tables 3 and 4 show the Shore A hardness, displacement, water sorption and solubility, and the color change after two types of coloring solution immersion.

**Hardness**

The Shore A hardness after 24 hours ranged from 33.2 for SR13F to 47.7 for VS; while that after 1 week ranged from 31.4 for SR13F to 47.9 for VS. Two-way ANOVA revealed that only main factor of lining material was significant ($p<0.0001$). The Shore A hardness of SR13F was significantly smaller than those of the others. There was no significant difference between SR12F and MB.

**Viscoelastic properties**

The examined soft lining materials were classified as two types according to the viscoelastic behavior: elastic material with almost no viscosity (MB) and elastic materials with viscosity (SR12F, SR13F, and VS). The instantaneous elastic displacements after 24 hours ranged from 0.22 mm for SR12F to 0.79 mm for MB; while those after 1 week ranged from 0.14 mm for SR12F to 0.76 mm for MB. Two-way ANOVA suggested that two main factors, lining materials ($p<0.0001$) and immersion period ($p<0.0001$), and their interaction were significant ($p<0.0001$). The immersion period significantly decreased the instantaneous elastic displacements of SR12F and VS, however, it did not change the instantaneous elastic displacements of SR13F and MB. Instantaneous elastic displacement of MB was significantly greater than those of the others. The delayed elastic displacements after 24 hours ranged from 0.03 mm for MB to 0.50 mm for SR13F; while those after 1 week ranged from 0.03 mm for MB to 0.53 mm for SR13F. Two-way ANOVA suggested that one main factor, lining materials ($p<0.0001$) and interaction between lining materials and immersion period were significant ($p=0.0055$). The immersion period significantly decreased the delayed elastic displacement of SR12F, however, it did not change the delayed elastic displacements of the other materials. The delayed elastic displacement of MB was significantly smaller than those of the others. The viscous flow ranged from 0.01 mm for MB to 0.17 mm for SR13F; while those after 1 week ranged from 0.01 mm for MB to 0.16 mm for SR13F. Two-way ANOVA suggested that one main factor, lining materials ($p<0.0001$) and interaction between lining materials and immersion period were significant ($p=0.0002$). The immersion period significantly decreased the viscous flow of SR12F, however, it did not change the viscous flow of the other materials. The viscous flow of SR 13F was significantly greater than those of the others. The residual displacement ranged from 0.03 mm for MB to

### Table 3 Mean (SD) of Shore A hardness and displacement of lining materials

<table>
<thead>
<tr>
<th>Code</th>
<th>Shore A hardness</th>
<th>Instantaneous elastic displacement</th>
<th>Delayed elastic displacement</th>
<th>Viscous flow</th>
<th>Residual displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>24 hours</td>
<td>1 week</td>
<td>24 hours</td>
<td>1 week</td>
</tr>
<tr>
<td>SR12F</td>
<td></td>
<td>42.3 (2.7) b</td>
<td>44.8 (4.3) b</td>
<td>0.22 (0.01) j</td>
<td>0.14 (0.03) k</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.29 (0.04) h</td>
<td>0.18 (0.03) k</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.11 (0.03) j</td>
<td>0.05 (0.00) n</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.30 (0.04) a</td>
<td>0.13 (0.02) a</td>
</tr>
<tr>
<td>SR13F</td>
<td></td>
<td>33.2 (3.8) c</td>
<td>31.4 (4.1) c</td>
<td>0.36 (0.05) e</td>
<td>0.35 (0.05) e</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.50 (0.04) j</td>
<td>0.53 (0.11) i</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.17 (0.01) m</td>
<td>0.16 (0.04) m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.54 (0.02) s</td>
<td>0.48 (0.11) s</td>
</tr>
<tr>
<td>VS</td>
<td></td>
<td>47.7 (1.6) b</td>
<td>47.9 (1.7) b</td>
<td>0.41 (0.00) e</td>
<td>0.21 (0.01) k</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.49 (0.03) i</td>
<td>0.51 (0.02) i</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.07 (0.00) j</td>
<td>0.09 (0.00) j</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.16 (0.00) p</td>
<td>0.11 (0.01) p</td>
</tr>
<tr>
<td>MB</td>
<td></td>
<td>42.8 (0.5) b</td>
<td>42.2 (0.8) b</td>
<td>0.79 (0.04) f</td>
<td>0.76 (0.06) f</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.03 (0.03) i</td>
<td>0.03 (0.02) i</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.01 (0.00) o</td>
<td>0.01 (0.00) o</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.03 (0.00) p</td>
<td>0.03 (0.02) p</td>
</tr>
</tbody>
</table>

Within column, groups having the same superscript letter are not statistically different ($p>0.05$). $n=5$

### Table 4 Mean (SD) of water sorption, solubility, color change of lining materials

<table>
<thead>
<tr>
<th>Code</th>
<th>Water sorption ($\mu g/mm^3$)</th>
<th>Solubility ($\mu g/mm^3$)</th>
<th>Color change ($\Delta E$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coffee $\beta$-carotene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR12F</td>
<td>12.52 (2.03)$^a$</td>
<td>3.11 (0.65)$^a$</td>
<td>12.54 (1.57)$^g$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.44 (0.43)$^j$</td>
</tr>
<tr>
<td>SR13F</td>
<td>10.00 (0.80)$^b$</td>
<td>2.33 (0.47)$^a$</td>
<td>11.20 (1.27)$^g$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.51 (0.33)$^j$</td>
</tr>
<tr>
<td>VS</td>
<td>18.34 (1.22)$^c$</td>
<td>6.13 (0.96)$^f$</td>
<td>25.99 (1.05)$^b$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.65 (0.32)$^j$</td>
</tr>
<tr>
<td>MB</td>
<td>3.75 (0.50)$^d$</td>
<td>2.53 (0.45)$^c$</td>
<td>3.10 (0.57)$^i$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18.53 (3.15)$^k$</td>
</tr>
</tbody>
</table>

Within column, groups having the same superscript letter are not statistically different ($p>0.05$). $n=5$
0.54 mm for SR13F; while those after 1 week ranged from 0.03 mm for MB to 0.48 mm for SR13F. Two-way ANOVA suggested that two main factors, lining materials ($p<0.0001$) and immersion period ($p=0.0001$), and their interaction were significant ($p=0.0005$). The immersion period significantly decreased the residual displacement of SR12F, however, it did not change the residual displacements of the other materials.

**Water sorption and solubility**

Water sorption ranged from 3.75 µg/mm³ for MB to 18.34 µg/mm³ for VS. The fluorinated soft lining materials SR12F and SR13F both showed a significantly lower water sorption than VS. The solubility ranged from 2.33 µg/mm³ for SR13F to 6.13 µg/mm³ for VS. In addition, no significant difference was observed among SR12F, SR13F, and MB.

**Staining resistance**

Widely varying staining resistances were found among the four soft lining materials. The $\Delta E$ in coffee solution ranged from 3.10 for MB to 25.99 for VS. The $\Delta E$ of SR12F and SR13F were significantly lower than that of VS. The $\Delta E$ in $\beta$-carotene/olive oil solution ranged from 4.44 for SR12F to 18.53 for MB. The $\Delta E$ of MB was significantly greater than those of the others.

**DISCUSSION**

Desirable properties for soft lining materials include long-term stable viscoelastic behavior, low water sorption, good staining resistance, high bond strength to the denture base, dimensional stability, ease of processing and biocompatibility. The fluorinated soft lining material, KPD, has been reported to satisfy almost all these properties23,24, but it is not commercially available at present. The incorporation of dodecafluoroethyl methacrylate (12F) and tridecafluoroctyl methacrylate (13F) increases the number of fluorine atoms per molecule, which may enhance the characteristics of fluorocarbon polymers. Based on this concept, SR12F and SR13F were prepared. Properties of these fluorinated materials were evaluated for clinical application compared to that of conventional popular materials.

MB is a conventional silicone rubber-based soft lining material, whose properties have been widely-reported. The Shore A hardness, water sorption, solubility, $\Delta E$ in coffee solution and $\Delta E$ in $\beta$-carotene/olive oil solution of MB were reported as 41.8, 3.82 µg/ mm³, 1.27 µg/mm³, 7.78 and 9.80, respectively33. The amounts of instantaneous elastic displacement, delayed elastic displacement and viscous flow reported by Muraoka et al.27 were 0.63–0.67 mm, 0.03–0.05 mm and 0.00–0.05 mm, respectively. Except for staining resistance, these values were almost identical to those measured in this study. Regarding staining resistance, the period of staining solution immersion in the previous study was 24 hours, but was 7 days in the present study; as a result, the staining resistance in this study was greater than that in the previous study. In a previous study, the $\Delta E$s in coffee and $\beta$-carotene/olive oil solution of SR12F were reported to be 3.14 and 1.00, respectively, while; those of VS were reported to be 14.94 and 1.90, respectively30. The SR12F and VS used in that previous study included red pigments, but those used in the present study did not include red pigments. As a result, the $\Delta E$ value in the present study was greater than that in the previous study.

The clinically appropriate Shore A hardness for soft lining materials has not yet been clarified. Hayakawa et al.20 reported a Shore A hardness of 42 for dough-type fluoropolymer soft lining materials containing difluoroethylene, chlorotrifluoroethylene and tetrafluoroethylene as fluorinated monomers. Ohe et al.30 evaluated effects of the side chain of the fluorinated monomers on Shore A hardness and concluded Shore A hardness decreased when the side chain increased. The Shore A hardness of SR13F was smaller than those of SR12F and KPD because the side chain of 13F was greater than those of 12F and those of the three fluorinated monomers in KPD. The application of soft lining materials with viscoelastic behavior close to that of mucosa has been reported to be preferable, compared to elastic materials such as silicone rubber-based soft lining materials in the clinical situation11. A hardness test, such as the Shore A hardness test has been employed by many researchers14,16,24,25,29. There was no significant difference between Shore A hardness of SR12F and MB. However, the viscoelastic behavior of SR12F was significantly different from that of MB. Moreover, Shore A hardness did not change after 1 week of storage, but viscoelastic behavior of SR12F and VS changed after 1 week of storage. Consequently, it was reconfirmed that the evaluation using Shore A hardness could not appropriately demonstrate the viscoelastic behavior.

Soft lining materials are expected to absorb, relieve and uniformly distribute the biting force during mastication. The viscoelastic properties of the soft lining materials are known to influence these functions. Therefore, the viscoelastic properties with dynamic and static measurements are suggested30. Dynamic measurements are generally performed using very rapid movements, but the actual mastication movement is not so rapid. Consequently, static viscoelastic measurements are more desirable to simulate the actual mastication movement30. The creep-meter is able to measure displacement precisely and it is therefore suitable for static viscoelastic measurements. Grant et al.25 reported MB to be the most elastic material in comparison to another silicone rubber-based material and acrylic-based materials. Wagner et al.18 also suggested that MB displays no viscosity. Murata et al.19 reported that acrylic-based materials show viscoelastic properties and the silicone rubber-based materials mainly exhibit elastic properties. In the present study, SR12F, SR13F and VS showed greater viscous flow compared to VS and MB. These results suggest that the experimental fluorinated soft lining materials could thereby relieve the forces generated during mastication. SR12F and
SR13F indicated a greater residual deformation in comparison to VS and MB. A greater residual deformation suggests a greater relief effect of the damaged mucosa, but risk of decrease of total occlusal dimension. Therefore, the usage of SR12F and SR13F should be eliminated only where the mucosa is damaged. After 1 week of storage, the viscoelastic properties of SR13F and MB did not change. SR13F was higher molecular and more containing fluorine atoms compared with SR12F, and MB was silicone-based material and hydrophobic. Therefore, SR13F and MB were more stable than SR12F and VS.

High water sorption and solubility of the soft lining materials can cause dimensional change, a loss of resilience, discoloration and bad odors, and can also separate from the denture base. Additionally, solubility represents a loss of components during immersion and the eluted substances can sometimes irritate the oral mucosa.\(^8,9\) Water sorption depends on the degree of hydrophobicity and porosity of the material.\(^23\) The gradual leaching of plasticisers and residual monomers out of the soft lining materials also causes clinical problems. The electronegativity of the fluorine atom is highest. When the surface of a solid is covered with fluorine atoms the surface energy decreases. Therefore, the surface of a material containing fluorine atoms is considered to be minimally permeable to liquids with a high molecular cohesion and water-repellent properties, thus leading to a decrease in water sorption. SR12F and SR13F, which are both fluorinated soft lining materials, showed a significantly lower solubility than VS. This finding suggests that fluorinated monomers are barely eluted in water, unlike acrylic monomers.\(^16\) It is also predicted that the degradation of the materials by the eluted constituents and stimulation of the oral mucosa would be minimal.

An optimal soft lining material should not be easily stained or discolored. Several factors may contribute to the discoloration of denture base materials after long-term use. These factors include stain accumulation, water sorption, the dissolution of ingredients, and the degradation of intrinsic pigments. It is well-known that beverages such as tea, coffee, wine, and some artificial colorants used in food rapidly increase the discoloration of restorative materials. Two staining solutions were chosen for this staining resistance test: coffee solution and \(\beta\)-carotene/olive oil solution. Tannic acid (\(\text{C}_{14}\text{H}_{10}\text{O}_{9}\)) is present in coffee and tea. It is water-soluble and usually causes a brown dental stain. \(\beta\)-carotene (\(\text{C}_{40}\text{H}_{56}\)) is a popular water-insoluble colorant that is abundant in many kinds of foods. The use of fluorinated monomers for immersion in coffee solution induced the property of water repellency and allowed suppression of pigmentation. After being immersed in \(\beta\)-carotene/olive oil solution, SR12F and SR13F showed less color change than MB, but a similar color change to that of VS. VS, an acrylic resin-based material, is more hydrophilic than MB, which is a silicone-based material. SR12F and SR13F consisted of methoxy diethylene glycol methacrylate and silanized fumed silica which may be relatively more hydrophobic than acrylic resin; however, the introduction of fluorinated monomers produced a marked oil repellency. Therefore, only a small color change of SR12F, SR13F and VS was observed after immersion in \(\beta\)-carotene/olive oil solution.

Contaminating substances in the oral cavity are not only hydrophilic, but they can also be hydrophobic (e.g., lipids). When comparing these experimental materials and the commercial materials, the fluorinated soft lining materials showed less color change and adequate staining resistance.

The properties of soft lining materials are not adequately satisfied for clinical situations. Both acrylic- and silicone-based soft lining materials have disadvantages. The acrylic-based soft lining materials demonstrate viscoelastic behavior but are easily degraded, while the silicone-based materials are chemically stable but demonstrate an elastic behavior. In this study, SR12F and SR13F showed a greater viscous flow, low water sorption and solubility and good staining resistance. Especially SR13F exhibited no change in its viscoelastic properties after 1 week of storage. As a result, the soft lining materials containing fluorinated monomers such as SR13F, are therefore suggested to potentially have a long-term stable viscoelastic behavior.

**CONCLUSION**

Within the limitations of the present study, the following conclusions have been drawn:

1. SR12F and SR13F show a greater viscous flow, in comparison to VS and MB. MB mainly shows elastic displacement and only a slight viscous flow. The viscoelastic properties of SR13F and MB did not significantly change after 1 week of storage.

2. The water sorption and solubility of SR12F and SR13F are significantly smaller than those of VS. The water sorption and solubility of MB are the smallest among the examined materials.

3. Staining resistance in coffee solution of SR12F and SR13F is intermediate to that of VS and MB; staining resistance in \(\beta\)-carotene/olive oil solution of SR12F, SR13F and VS are significantly better than that of MB.

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