Effect of composition of experimental fluorinated soft lining materials on bond strength to denture base resin

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The purpose of the present study was to investigate the effect of the composition of experimental fluorinated soft lining materials on bond strength to denture base resin. Vinylidene fluoride/hexafluoro propylene copolymer (2-6F), tridecafluoroctyl methacrylate (13FMA), methoxy diethylene glycol methacrylate (MDGMA), and silica (as filler) were used for fabrication of the experimental soft lining materials. Nine experimental soft lining materials having various compositions of 2-6F, 13FMA, and MDGMA were prepared. Shear and tensile bond strength tests were performed before and after immersion in water. The water sorption for the materials was also measured. An increase in the content of acrylic monomer, MDGMA, in the experimental materials increased the bond strength before immersion in water but reduced the bond strength after immersion in water as compared to that before immersion in water. The inclusion of fluorinated monomer (13FMA) in the materials appeared to affect water sorption.

Keywords: Soft lining material, Fluorinated polymer, Bond strength

INTRODUCTION

Application of denture lining materials is an important procedure in prosthetic treatment for denture wearers complaining of masticatory pain. Denture-bearing tissues rarely withstand the forces transmitted by denture bases for long periods of time9. However, soft lining materials can be used to distribute the masticatory forces evenly to the soft tissues supporting the prostheses. Due to the fact that the tissue-contacting surface of removable dentures is covered with soft lining materials, patients are comfortable and, in some cases, a healing effect on the mucosa can be expected2-4.

At the present time, commercially available soft lining materials are made of acrylic polymers or silicone rubber materials5,6. Acrylic-based soft lining materials strongly adhere to the acrylic resin denture base, but the plasticizer added to the materials is known to gradually diffuse toward the material surface and leach out due to contact with saliva5. This results in hardening of the soft lining materials and loss of viscoelasticity with time. Bacterial contamination, which may be caused by the roughness of the material surface or the water sorption for the materials, is another problem associated with the use of the acrylic soft lining materials5. Furthermore, the elution of residual acrylic monomers is reported to produce unwanted soft tissue reactions, such as redness, irritation, swelling, and pain in oral mucosa9,10. On the other hand, silicone rubber-based soft lining materials are chemically stable compared to acrylic soft lining materials, and their elasticity can be maintained. However, it is difficult to adhere silicone rubber-based soft lining materials chemically to acrylic denture base. Therefore, adhesive agents should be applied to obtain sufficient bonding between silicone rubber-based lining materials and the denture base11. In addition, silicone rubber-based soft lining materials reportedly enhance the growth of fungi such as Candida albicans on the material surface in the presence of saliva12.

An attempt has been made to apply fluorocarbon polymers to dental materials because of their excellent characteristics as dental materials, such as chemical stability, water and oil repellency, and contamination resistance13,14. A commercial fluoropolymer soft lining material (Kurepeet (KP), Kurecha Co., Tokyo, Japan), developed by Hayakawa et al., exhibited extremely low water sorption and excellent adhesion to acrylic resins15. A dough-type fluoropolymer soft lining material (Kurepeet Dough, Kurecha Co., Tokyo, Japan) was later developed to improve the usability and softness of KP without sacrificing its excellent physical properties16. These fluoropolymer soft lining materials, however, are not available on the market at present because the carbon tetrachloride generated during the production process of fluoropolymers was banned by the Montreal Protocol17.

Therefore, the development of a production process for fluoropolymer soft lining material that does not generate carbon tetrachloride was initiated18-20. In previous studies, experimental materials containing trifluoroactryl methacrylate, which can be synthesized without generating carbon tetrachloride,
exhibited greater viscous flow, low water sorption, low solubility, and good staining resistance compared to commercial products. 

Although the experimental fluoropolymer lining materials reported in these previous studies exhibit promising material characteristics for clinical application in the future, the adhesive properties of these experimental materials to the denture base remain unknown. Reliable adhesion of the lining material to the denture base is required in order to achieve proper function and long service life in the lining materials. However, the difficulty in obtaining a reliable bond between soft lining materials and (polymethyl methacrylate) (PMMA) denture-base polymers has often been discussed in previous studies. The most common clinical failure of soft lining materials was attributed to rupture of the bond between the lining material and the denture base. Therefore, determination of the characteristics of this bond is believed to be clinically relevant. The purpose of the present study is to investigate the effect of the composition of the experimental fluorinated polymer soft lining materials on the bond strength to denture base resin.

**MATERIALS AND METHODS**

**Materials**

The materials used for preparation of the experimental soft lining materials are listed in Table 1. Vinylidene fluoride/hexafluoro propylene copolymer (2-6F) as a fluorinated polymer, tridecafluoroctyl methacrylate (13FMA) as a fluorinated monomer, methoxy diethylene glycol methacrylate (MDGMA) as an acrylic monomer, and silica as a filler are used for fabrication of the experimental soft lining materials. The molecular formulas of 2-6F, 13FMA, and MDGMA are shown in Fig. 1. The fluorinated polymer 2-6F had approximately 3,000 of molecular weight. These components were chosen for use in the present study according to compositions used in a previous study.

In the present study, we prepared two groups of experimental soft lining materials with different compositions in order to examine the effects of the components. The first group consisted of five different soft lining materials with identical contents of 2-6F (56%) and varying contents of MDGMA and 13FMA (Table 2). The second group consisted of five different lining materials with identical contents of 13FMA (12%) and varying contents of 2-6F and MDGMA (Table 3). In the present study, F12 had a composition identical to that of P56. In order to initiate polymerization, 0.4 mass% of benzoyl peroxide (benzoyl peroxide 1st grade Saj, Sigma Aldrich, St. Louis, USA) was added to all of the experimental lining materials.

Two different commercially available soft lining materials were also examined: “VertexSoft clear” as an acrylic-based soft lining material (VS, Vertex Dental B.V, Zeist, Netherlands) and “Molloplast-B” as a silicone rubber-based soft lining material (MB, Detax, Ettlingen, Germany) (Table 4).

The polymerization process conditions for each soft lining material are summarized in Table 5, and the polymerization process conditions for the commercial lining materials were in accordance with the manufacturers' instructions.

**Methods**

1. Bond strength tests to denture base resin

1) Shear bond strength testing

(1) Specimen preparation


![Molecular formulas of 2-6F, 13FMA, and MDGMA.](image)

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Table 1 Chemical components used for experimental soft lining materials in the present study

<table>
<thead>
<tr>
<th>General name</th>
<th>Product name</th>
<th>Manufacturer</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinylidene fluoride/hexafluoro propylene</td>
<td>DAI-EL G-101</td>
<td>Daikin Industries, Osaka, Japan</td>
<td>2-6F</td>
</tr>
<tr>
<td>Tridecafluoroctyl methacrylate</td>
<td>M-1620</td>
<td>Daikin Chemicals, Osaka, Japan</td>
<td>13FMA</td>
</tr>
<tr>
<td>Methoxy diethylene glycol methacrylate</td>
<td>NK Ester M-20G</td>
<td>Shin-Nakamura Chemical, Wakayama, Japan</td>
<td>MDGMA</td>
</tr>
<tr>
<td>Fumed silica</td>
<td>R972, particle size: 16 nm</td>
<td>Nippon Aerosil, Tokyo, Japan</td>
<td>Silica</td>
</tr>
</tbody>
</table>
Table 2 Composition of experimental soft lining materials with varied contents of MDGMA and 13FMA

<table>
<thead>
<tr>
<th>Code</th>
<th>Polymer 2-6F</th>
<th>Monomer MDGMA</th>
<th>Monomer 13FMA</th>
<th>Filler Silica</th>
</tr>
</thead>
<tbody>
<tr>
<td>F0</td>
<td>56</td>
<td>24</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>F6</td>
<td>56</td>
<td>18</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>F12</td>
<td>56</td>
<td>12</td>
<td>12</td>
<td>20</td>
</tr>
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<td>F18</td>
<td>56</td>
<td>6</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>F24</td>
<td>56</td>
<td>0</td>
<td>24</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 3 Composition of experimental soft lining materials with varied contents of 2-6F and MDGMA

<table>
<thead>
<tr>
<th>Code</th>
<th>Polymer 2-6F</th>
<th>Monomer MDGMA</th>
<th>Monomer 13FMA</th>
<th>Filler Silica</th>
</tr>
</thead>
<tbody>
<tr>
<td>P56</td>
<td>56</td>
<td>12</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>P50</td>
<td>50</td>
<td>18</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>P44</td>
<td>44</td>
<td>24</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>P38</td>
<td>38</td>
<td>30</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>P32</td>
<td>32</td>
<td>36</td>
<td>12</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 4 Chemical composition of the commercial soft lining materials used in the present study

<table>
<thead>
<tr>
<th>Product</th>
<th>Manufacturer</th>
<th>Composition</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertex Soft liquid (Lot No.YG091L02) powder (Lot No.YH482P03)</td>
<td>Vertex Dental B.V., Zeist, Netherlands</td>
<td>Polyethyl methacrylate Ethyl methacrylate</td>
<td>VS</td>
</tr>
<tr>
<td>Molloplast-B (Lot No.131044)</td>
<td>Detax, Ettlingen, Germany</td>
<td>α-ω-dihydroxy end blocked polydimethyl siloxane</td>
<td>MB</td>
</tr>
</tbody>
</table>

Table 5 Processing conditions for the tested lining materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Processing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental lining materials</td>
<td>Mooring from 20 to 100°C for 120 min → 100°C for 30 min</td>
</tr>
<tr>
<td>VS</td>
<td>Start for 20°C → 70°C for 90 min → 100°C for 30 min</td>
</tr>
<tr>
<td>MB</td>
<td>Start for 20°C → 100°C for 2 h</td>
</tr>
</tbody>
</table>

GC, Tokyo, Japan) plates (15 mm×15 mm×5 mm) were used as substrates for bond strength testing (n=220). The acrylic resin plates were polymerized in dental flasks according to the normal procedures at 75°C for 8 h according to the manufacturer’s instructions. The acrylic resin plates were embedded in self-curing epoxy resin and ground using SiC abrasive paper (600 grit) under water and dried thoroughly at room temperature in air. The experimental lining materials were injected into Teflon rings with an inner diameter of 6 mm and a height of 3 mm and were polymerized according to the processing conditions shown in Table 5. After curing, the Teflon rings were removed, and excess areas of the soft lining materials were trimmed away using a sharp blade.

Twenty specimens were prepared and randomly divided into two groups of ten specimens (n=10). One group of specimens was stored in air at 23±2°C for one week (Group 1), and the other group was stored in air at 23±2°C and then immersed in distilled water at 37±2°C for one week (Group 2).

(2) Determination of shear bond strength and observation of fracture modes
Shear bond strength testing was performed using a universal testing machine (Instron 4302, Instron) at a crosshead speed of 10 mm/min in air at 23°C (Fig. 2). The shear bond strength of the specimen was calculated as follows:

\[ \sigma = \frac{F}{A} \]

where \( \sigma \) is the shear bond strength (MPa), \( F \) is the maximum recorded force at failure (N), and \( A \) is the original cross sectional area (mm²).

After testing, the specimens were observed visually, and the failure types were classified as follows: adhesive failure (no lining material left on the substrates), cohesive failure (failure within the lining material without substrates exposure), and mixed failure (lining material partially left on the substrates).

2) Tensile bond strength testing
(1) Specimen preparation
Heat-polymerizing denture-base acrylic resin was formed into two different shapes for use as substrates in
tensile bond strength tests \((n=220)\): a plate-shaped resin block \((15 \text{ mm} \times 15 \text{ mm} \times 5 \text{ mm})\) as a lower substrate and a cylindrical resin block \((\text{diameter}: 10 \text{ mm}, \text{height}: 10 \text{ mm})\) as an upper substrate. The acrylic resin plates were polymerized in dental flasks using normal procedures at \(75^\circ\text{C}\) for 8 h according to the manufacturer’s instructions. The plate-shaped lower substrates were embedded using self-cured epoxy resin and were ground under water using SiC abrasive paper \((600 \text{ grit})\). The top surfaces of the cylindrical substrates were also ground under water using SiC abrasive paper \((600 \text{ grit})\).

A polyvinyl chloride ring of \(6 \text{ mm}\) in inner diameter and \(1 \text{ mm}\) in height was placed at the center of the lower substrate and the lining material was injected into the polyvinyl chloride ring. After injection of the lining material, the top surface of the cylindrical upper substrate was placed on the ring filled with uncured lining material and the substrates were clamped. The lining materials were polymerized according to the conditions in Table 5. The polyvinyl ring was carefully removed after polymerization and excess soft lining material was trimmed away using a sharp blade.

Twenty specimens were prepared and randomly divided into two groups of ten specimens \((n=10)\). One group was stored in air at \(23\pm2^\circ\text{C}\) for one week (Group 1), and the other group was stored in air at \(23\pm2^\circ\text{C}\) and then immersed in distilled water at \(37\pm2^\circ\text{C}\) for one week (Group 2).

2. Determination of tensile bond strength and observation of fracture modes

Tensile bond testing was performed using a universal testing machine (Instron 4302, Instron) at a crosshead speed of \(10 \text{ mm/min}\) in air at \(23^\circ\text{C}\) (Fig. 3). The tensile bond strength of the specimen was calculated as follows:

\[
\sigma = \frac{F}{A}
\]

where \(\sigma\) is the tensile bond strength \((\text{MPa})\), \(F\) is the maximum recorded force at failure \((\text{N})\), and \(A\) is the original cross sectional area \((\text{mm}^2)\).

After testing, the failed specimens were observed visually, and the failure types were classified in the same manner as in the shear bond strength test.

3. Statistical analysis

The shear and tensile bond strengths were statistically analyzed by a two-way analysis of variance (ANOVA) followed by Tukey’s HSD test using statistical software (SPSS 17.0, SPSS, Chicago, IL, USA). The results of the water sorption measurements were statistically analyzed by a one-way ANOVA and Tukey’s HSD test. The significance level was set at 0.05.

RESULTS

Shear bond strength

The results of the shear bond strength test are presented in Figs. 4 and 5. Significant interaction between the factors (soft lining materials and aging) was found. Materials VS, F0, F6, P44, P38, and P32 exhibited significant lower shear bond strength after immersion.
in water for one week, as compared to the case in which these materials were not immersed in water. Materials P50, P44, P38, and P32 had greater bond strength than MB without immersion in water and after immersion in water. Materials F6, F12, F18 and F24 had significantly lower bond strength than VS in both aging conditions (\(p<0.05\)). The bond strengths of P56 and P50 materials without immersion in water were not significantly different as compared to VS. However, those of P44, P38 and P32 without immersion in water showed significantly greater than VS. For the specimens after immersion in water, materials P44 and P32 had significantly greater bond strength than VS and materials P56, P50 and P38 revealed no significant differences in bond strength compared to VS. All of the MB materials exhibited mixed failures, whereas all of the other materials exhibited cohesive failures (Table 6).

![Fig. 4](image1.png)  
**Fig. 4** Shear bond strengths of experimental soft lining materials with different MDGMA and 13FMA contents and commercial soft lining materials to denture base resin.  
Same upper-case letters indicate no statistical differences among the specimens without immersion in water \((p>0.05, n=10)\).  
Same lower-case letters indicate no statistical differences among the specimens immersed in water \((p>0.05, n=10)\).  
Bracket with * indicates statistical difference between specimens without immersion in water and after immersion in water at \(p<0.05\).

![Fig. 5](image2.png)  
**Fig. 5** Shear bond strengths of experimental soft lining materials with different 2-6F and MDGMA contents and commercial soft lining materials to denture base resin.  
Same upper-case letters indicate no statistical differences among the specimens without immersion in water \((p>0.05, n=10)\).  
Same lower-case letters indicate no statistical differences among the specimens immersed in water \((p>0.05, n=10)\).  
Bracket with * indicates statistical difference between specimens without immersion in water and after immersion in water at \(p<0.05\).

### Table 6  Distribution of failure type for shear-tested specimens

<table>
<thead>
<tr>
<th>Without immersion in water</th>
<th>After immersion in water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cohesive</strong></td>
<td><strong>Mixed</strong></td>
</tr>
<tr>
<td>MB</td>
<td>0</td>
</tr>
<tr>
<td>VS</td>
<td>10</td>
</tr>
<tr>
<td>F0</td>
<td>10</td>
</tr>
<tr>
<td>F6</td>
<td>10</td>
</tr>
<tr>
<td>F12</td>
<td>10</td>
</tr>
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<td>10</td>
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<td>P50</td>
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<td>10</td>
</tr>
<tr>
<td>P38</td>
<td>10</td>
</tr>
<tr>
<td>P32</td>
<td>10</td>
</tr>
</tbody>
</table>
Tensile bond strength

Figures 6 and 7 show the results of the tensile bond strength test. No significant interaction was observed between the factors (soft lining materials and aging). Material VS showed significantly higher bond strength than other materials. There were no significant differences in bond strength among F6, F12, F18, F24 materials without or after immersion in water \((p>0.05)\). No statistical differences in bond strength were also found among MB, F0, F6, F18 and F24 materials in all specimen storage conditions \((p>0.05)\). For both the specimens without and after immersion in water, materials P44, P38, P32 and MB did not have significant different bond strength and have significantly greater bond strength than P50 material. The failure mode frequency after debonding is listed for each tested condition in Table 7. Most of the experimental materials exhibited cohesive failures, whereas materials MB and VS exhibited adhesive failures.

Water sorption

The results of the water sorption test are shown in Figs. 8 and 9. The mean values for water sorption for the experimental soft lining materials ranged from 6.8 \(\mu\)g/mm\(^3\) (F24) to 56.1 \(\mu\)g/mm\(^3\) (F0). Material F0 exhibited significantly greater water sorption than the

Table 7  Distribution of failure type for tensile-tested specimens

<table>
<thead>
<tr>
<th></th>
<th>Without immersion in water</th>
<th></th>
<th>After immersion in water</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cohesive</td>
<td>Mixed</td>
<td>Adhesive</td>
<td>Cohesive</td>
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<tr>
<td>MB</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0</td>
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<tr>
<td>VS</td>
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<td>0</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>F0</td>
<td>10</td>
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<td>0</td>
<td>10</td>
</tr>
<tr>
<td>F6</td>
<td>8</td>
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<td>2</td>
<td>10</td>
</tr>
<tr>
<td>F12</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>F18</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>10</td>
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<td>0</td>
<td>8</td>
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<td>P50</td>
<td>9</td>
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<td>10</td>
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<td>P44</td>
<td>10</td>
<td>0</td>
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<td>9</td>
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<td>P38</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>8</td>
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</tbody>
</table>
other materials. There were no significant differences among VS, F12, and F18 or between MB and F24. The commercial acrylic-based soft lining material VS showed significantly greater water sorption than commercial silicone rubber-based soft lining material MB. For the experimental materials containing different content ratios of 2-6F and MDGMA (P group materials), material P32 had the greatest water sorption among the experimental materials and an increase in the content of MDGMA increases the water sorption of the experimental materials (Fig. 9). These P group materials exhibited significantly greater water sorption than MB. Materials VS had significantly lower water sorption than materials P50, P44, P38 and P32.

The relationships between the measured amounts of water sorption and the reduction of the shear bond strength after immersion in water are shown in Fig. 10. In this figure, the reduction in the shear bond strength (Δ) is defined as the bond strength before immersion in water subtracted by the bond strength value after immersion in water. The coefficient of correlation was found to be 0.647, indicating an intermediate positive correlation between the water sorption and the reduction in the shear bond strength.

**DISCUSSION**

The present study was conducted in order to examine the effect of the composition of experimental fluorinated polymer soft lining materials on bond strength to denture base resin. The water sorption behavior of the experimental soft lining materials was also examined in order to investigate the relationship between the bonding behavior and the water sorption for lining materials.

For the long-term use of soft lining materials, bonding of the lining materials to the denture base is an important factor for clinical success. There are several methods by which to test the bond strength of materials. The measured bond strength is known to be influenced by the test method. Clinical failure mechanisms in bonding are complex because the materials are subject to various types of stresses in various directions. It has been reported that peel and shear testing methods can simulate the debonding behavior of dental materials in an actual oral cavity better than tensile testing methods. However, the complexity of the failure mechanisms and the higher probability of cohesive failures in the adherent using these test methods make interpreting the test results very difficult. Al-Athel and Jagger compared the test methods for bond strength of soft silicone-rubber based resilient lining material to denture base and concluded that the peel test was the least satisfactory test method for evaluating the bond strength of resilient lining material if the resilient lining material failed cohesively during test. As shown in Tables 6 and 7, a majority of the materials showed cohesive failure in the peel test.
experimental soft lining materials exhibited cohesive failure in this study. Thus, the shear or tensile testing method was considered to be appropriate to examine the adhesive behavior of the experimental soft lining materials in the present experimental conditions. In addition, the present study evaluated the bond strength of a lining material to denture base resin by both shear and tensile testing methods in which the debonding loads were applied from different directions in order to characterize the debonding behavior of the experimental lining materials.

Under the condition in which the specimens were not immersed in water, material P32, which contained the greatest content of MDGMA, exhibited significantly higher shear and tensile bond strengths than materials P56 and P50. This implies that an increase in the content of MDGMA increases the cohesive strength of the experimental materials before immersion in water.

The soft lining materials are subjected to be exposed to saliva or oral fluid during clinical service. The soluble components are leached out of the lining materials to saliva and the saliva or water is absorbed into the lining materials. The presence of saliva or ambient water is likely to affect the properties of soft lining materials and the bonding behavior of lining materials to denture base. Thus, the soft lining materials should have lower water sorption to exhibit stable performance in the oral cavity. The results of the present study revealed that the experimental soft lining material that did not contain fluorinated monomer (F0) had significantly greater water sorption than other materials.

As the content of the fluorinated monomer in the lining material increased, the water sorption for experimental soft lining material decreased. Acrylic resins are known to absorb water slowly over a period of time, primarily because of the polar properties of the resin molecules. Water sorption, in general, depends on the degree of hydrophobicity and the porosity of the material. Since the fluorine atom has the highest electronegativity, the surface energy of fluorinated polymer becomes low. Therefore, the fluorinated polymer is inert and hydrophobic. Thus, experimental soft lining materials that include large amounts of fluorinated monomers are considered to have lower water sorption.

According to Fig. 1, 2-6F has a higher molar concentration of fluorine atoms than 13FMA. For example, the amount of fluorine atoms in material F6 increased a maximum of 10% compared to F0. However, the water sorption for material F6, which contained a minimal amount of 13FMA, decreased greatly. Thus, the results suggested that a decrease in MDGMA and an increase in 13FMA further reduced the water sorption of the soft lining materials.

Several studies have evaluated the effect of water on the bond strength of soft lining materials. Polyzois reported that water storage reduced the bond strength of soft lining materials. The properties of a conventional silicone rubber-based soft lining material, MB, used in the present study, have been widely reported. Aydin reported that the bond strength of MB to denture base was not affected by water immersion and was acceptable for clinical use. The present study, however, demonstrated that the experimental materials F0, F6, P44, P38, and P32 exhibited significantly lower shear bond strengths after immersion in water, as compared to their shear bond strengths before immersion. An increase in the content of acrylic monomer in the experimental materials may decrease the bond strength after immersion in water as compared to that before immersion in water. A positive intermediate correlation (r=0.647) between the water sorption and the reduction in the shear bond strength was found (Fig. 10), which suggests that the water sorption behavior could affect the bond strength of lining materials that contain an acrylic monomer such as MDGMA and that MDGMA in the experimental lining materials, rather than 13FMA, would contribute to adhesion to denture base.

Although some of the tested materials exhibited reduced shear bond strength after immersion in water for one week, the measured tensile bond strengths were not significantly reduced after immersion in water. In a preliminary study, we examined the changes in the amounts of water sorption for soft lining materials and denture-base resin after immersion in water for up to nine days. The preliminary study revealed only slight changes in water sorption after immersion for three days. Polyzois reported that even the bond strength of a silicone rubber-based soft lining material, which absorbs a very small quantity of water, decreased after immersion in water for four months. The reduction in bond strength is assumed to have occurred because water intrudes through the adhesion interface when the lining materials are immersed in water for longer than one week. Further study is necessary in order to examine the effect of longer-term immersion on the bond strength of lining materials to denture base.

Examination of failure types in soft lining materials is useful for interpreting the results of bond strength tests. When the material fails cohesively, the cohesive strength of the material should be lower than the adhesive force. Since the bond failures within the lining material observed in the present study were predominantly cohesive, the true bond strength is assumed to be greater than the measured bond strength. Therefore, cohesive failures provide information related to the material strength rather than to the bond between materials. However, mixed and adhesive failures were observed in some specimens, indicating that the cohesive strength values of the lining materials and bond strength values to base resin were similar. In shear bond strength testing, all MB specimens exhibited mixed failures, whereas the VS specimens and all of the experimental materials exhibited cohesive failures. The results of the present study suggest that the adhesive force of soft lining materials are greater than indicated by the results of shear bond strength tests. Uptake of water can soften an acrylic resin because the absorbed water can act as a plasticizer of acrylate and can reduce the strength of the material. The bond strength measured in the present study was thought to
be lower after immersion in water because the water sorption increased due to an increase in the content of acrylic monomers in the lining materials, and this increase in water sorption is believed to have softened the lining materials. In tensile bond strength testing, all MB and VS specimens exhibited adhesive failures. The experimental soft lining materials other than F18 exhibited mostly cohesive failures, but F18 exhibited predominantly mixed failures. Therefore, as the content of the fluorinated monomer increased, the bond strength appeared to decrease. Material F24 exhibited mostly cohesive failures and was thought to be more brittle than the other experimental soft lining materials, because this material does not contain acrylic monomers.

In summary, the present study revealed that the bond strengths of experimental lining materials were equal to or greater than clinically used soft lining material MB. In the experimental soft lining materials, an increase in the content of acrylic monomer increases the bond strength before immersion in water. Moreover, the inclusion of fluorinated monomers appears to improve water sorption and bonding durability to denture base resin. The results of the present study suggest the possibility of developing a fluorinated soft lining material that would be acceptable for clinical application by further exploring suitable compositions.

ACKNOWLEDGMENTS

This work was supported by the Research Funding for Longevity Sciences (23-20) from National Center for Geriatrics and Gerontology (NCGG), Japan.

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