**In Vitro Evaluation of the Relationship between the Surface Properties and Retention Force of Resilient Liners and Conventional Liners**

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**Abstract**

*Purpose:* The aims of this in vitro study were to examine the surface properties of three types of relining materials using scanning electron microscopy (SEM), determine surface roughness and wettability of the materials, and identify the factors that affect the retention force of the materials.

*Methods:* Measurements were performed using a simple model to evaluate the retention force, contact angle, and surface roughness of resilient and conventional denture liners. Two types of commercially available resilient denture lining materials (SOFRELINER TOUGH MEDIUM and SOFRELINER TOUGH SUPER SOFT) and a hard denture relining material (TOKUYAMA REBASE III NORMAL) were examined. The retention force and contact angle were measured for the three materials under the same conditions, with three different intervening liquids used for each relining material. Multiple regression analysis was performed to investigate the effects of the contact angle, surface roughness, and rubber hardness on the retention force of the test specimens.

*Results:* Multiple regression analysis adjusting for type of material and type of intervening liquid revealed a significant association between the retention force and the contact angle (*P* < 0.001). In contrast, surface roughness showed no significant association with the retention force (*P* = 0.850).

*Conclusion:* The results of this study suggest that the surface roughness of the denture relining material does not affect its retention force.

**Keywords:** resilient denture liners, conventional denture liners, surface properties, retention, complete denture

**Introduction**

Although the number of elderly people with natural teeth is increasing due to the rapid growth in the global elderly population, a significant number of elderly people exhibit edentulism (1, 2). According to reports, 90% of Japanese people receive prosthetic dental treatment, and 88% of elderly people need dentures (3). Additionally, the number of denture wearers is increasing with the advent of a super-aged society (4). People who wear complete dentures may have problems with retention and stability of the denture when eating, difficulty in cleaning dentures, denture-related pain, loss of occlusal strength, and poor aesthetics.

Many complete denture wearers have problems with the retention and stability of their mandibular dentures. Several reports have shown that the poor retention and stability of complete dentures are associated with patient dissatisfaction and a poor quality of life (5–10). Denture retention depends on the thickness of the saliva between the mucosal surface of the denture and the jaw crest. Moreover, the amount and viscosity of saliva influence the retention (11). For the denture to be retained suffi-
ciently with the mucosa, there must be an adequate amount and a thin layer of moderate viscosity saliva between the denture mucosal surface and the jaw crest (12–14). To obtain this thin layer of saliva, a well-fitted denture mucosal surface and the jaw crest are required. However, if the fit is reduced due to denture crest resorption over time, the denture mucosal surface can be relined using hard polymethyl methacrylate (PMMA) or soft silicone materials.

There is a clinical report demonstrating that the retention of a silicone relining material is better than that of a hard relining material (15). This difference may be due to a difference in the wettability of saliva interposed between the denture mucosal surface and the jaw crest (16, 17). It was also speculated that the roughness of the denture mucosal surface might affect the difference in retention force. However, no reports have examined whether these factors directly affect retention under conditions in which different materials and different viscous liquids are interposed between the denture mucosal surface and the jaw crest.

Therefore, the aims of this in vitro study were to examine the surface properties of three types of relining materials using scanning electron microscopy (SEM), determine their surface roughness and wettability, and identify the factors that affect the retention force of the materials.

**Materials and Methods**

The materials used in the experiment are shown in Table 1. Heat curing acrylic resin denture base (URBAN, Shofu, Kyoto, Japan) was used as the denture base resin. The experiments compared two commercially available resilient denture lining materials with low rubber hardness (SOFRELINER TOUGH MEDIUM, Tokuyama, Tokyo, Japan [RT-M] and SOFRELINER TOUGH SUPER SOFT, Tokuyama, Tokyo, Japan [RT-S]) and a hard denture relining material (TOKUYAMA REBASE III NORMAL, Tokuyama, Tokyo, Japan [HR]) which served as the control.

**Design of the test specimen**

The specimen was made in the shape of a disk using acrylic resin. One side of the specimen was relined with the denture relining material. The surface area was 50 mm in diameter. This was close to the median value because the support area of the mandible is 14 to 24 cm² (18, 19). The thickness of the resilient denture relining material was 2 mm according to the instructions in the product description.

**Preparation of the resin block**

Resin blocks for lathe manufacturing were fabricated. A columnar paraffin wax (75 mm in diameter and 60 mm in height) was prepared and added to a maxillary metal flask (Whip Mix Co., Kentucky, USA) using gypsum (Dental Plaster, Mutsumi, Mie, Japan). After the plaster had hardened, the paraffin wax was melted and replaced with a heat-curing acrylic resin, and then it was polymerized using a heat-curing machine (Aqua Marathon, Dentronics, Tokyo, Japan) (Fig. 1i ~ v).

**Fabrication of the denture base resin**

Test specimens were manufactured from resin blocks (Fig. 2A). Lathe manufacturing was performed using numerical control machine tools (SP-CHP, Shizuoka Iron Works, Shizuoka, Japan) and NC lathes (SL-25, DMG MORI CO., LTD., Nagoya, Japan). The test specimens were made of resin with a diameter of 50 mm and a height of 8 mm and were manufactured by lathe processing from a resin block as a single block with a high-cylindrical flask with a diameter of 65 mm and a height of 5 mm on the opposite side of the test surface to be relined (Fig. 1vi, Fig. 2A). Three base resins were machined from one resin block. A stainless-steel eyebolt (IB-4M, Mizumoto Machine Mfg. Co., Ltd., Hyogo, Japan) was at-
Attached to the center of the flask tray with an M4 screw hole (Fig. 2 B). A part of the stainless-steel eyebolt was processed into a shape to attach to the traction line. Twenty-one test specimens were prepared, and 7 specimens were allocated to each group.

Fabrication of the spacing flask and installation in the base resin

To standardize the thickness of the relining material to 2 mm, a spacing flask was fabricated and installed in the base resin part of the test specimen (Fig. 1 vii). The spacing flask was made of a polytetrafluoroethylene (PTFE) block (Teflon, DuPont, Delaware, USA). The flask was made such that it had a 70 mm outer diameter, 50 mm inner diameter, and 10 mm height (Fig. 3A). When the spacing flask was fitted, a 3 mm wide groove was provided to open the flask.

Injection of the denture lining material

After treating the surface of the base resin with a primer (Sofreliner Tough Primer, Tokuyama, Tokyo, Japan), the base resin and the spacing flask were fitted together and the resilient denture lining material was injected (Fig. 1 viii, Fig. 2 D). Similarly, for the injection of the conventional denture lining material, the surface treatment was performed using the primer (Tokuyama Rebase Adhesives, Tokuyama, Tokyo, Japan) specified by the manufacturer. After injection, it was gently pressed against a glass plate and fixed under a pressure of 1 MPa using a hydraulic flask press (FP7, Morita, Tokyo, Japan). Each material was left at room temperature for 30 min, and after the polymerization was confirmed, the spacing
flask was carefully removed to complete the specimen (Fig. 1, ix, Fig. 4 A, B).

**Preparation of the simulated jaw crest**

A plate made of PTFE (diameter of 70 mm, thickness of 10 mm) was fabricated by lathing as a part corresponding to the simulated jaw crest (Fig. 5 A). The surface of the PTFE plate was first mechanically polished with water-resistant paper (EA366C-200, ESCO, Osaka, Japan) with a grain size of #2000. Protrusions (50 mm × 20 mm × 10 mm) for fixing were attached to the opposite side of the PTFE plate and fixed with screws (Fig. 5 B).

**Preparation of the intervening liquid**

A solution prepared by diluting a glycerin aqueous solution (Kenei Pharmaceutical, Osaka, Japan) was used as the intervening liquid between the specimens and the simulated mucosa. Assuming the viscosity of human saliva, the simulated intervening liquid was produced with 40% and 80% glycerin aqueous solution (high viscosity) (20). In addition, purified water (Kenei Pharmaceutical Co., Ltd., Osaka, Japan) without glycerin was used as a control. A tensile test was performed with each intervening liquid interposed.

**Measurement of retention force by the tensile test**

For the tensile test, a universal tensile compression tester (Techno Graph TG-5kN, MinebeaMitsumi, Nagano, Japan) was used. It has been reported that the cohesive force of the intervening saliva is maximized when the distance between the denture base and the oral mucosa is minimal, thereby yielding the highest retention force of the denture base (12). Therefore, the experimental system was set up to minimize the distance between the two horizontal plates. The plates were fixed on a universal tester so that the PTFE plate was horizontal. The intervening liquid (10 ml) was gently dropped into the center of the PTFE plate using a micropipette, and the relined surface of the specimens was gently placed on the PTFE plate.

The average occlusal force of complete denture wearers was 3.4 kgf (21). To simplify the operation and to prevent non-vertical forces from being applied when removing the load on the experiment, the load holding time was set to 10 seconds when the preliminary experiment was performed and the load was set to 2 kgf. In all of the subsequent experiments, the load was set to 2 kgf and the load holding time was set to 10 seconds. After the load was completed, the traction line was quickly connected to the specimens. A stainless-steel chain was used for the traction line, and the gauge length was set to 200 mm (Fig. 6).

The retention force was measured for the three types of denture relining materials. It was then measured under the same conditions using three types of intervening liquid for each relining material. The measurement was repeated 10 times for each intervening liquid (a temperature of 23°C ± 2°C and relative humidity of 50% ± 10%).

**Water contact angle**

The water contact angle was measured using a contact angle meter (CA-DT, Kyowa Interface Science Co. Static electricity was removed from the surface of the specimen with an ionizing air blower (AIN-CDC, ASPPURE Co., Ltd., Hyogo). Next, the contact angle was measured 5 seconds after applying one drop of intercalation solution.
(2 µl) to the surface of the specimen. Measurements were made five times at different locations, and the mean and standard deviation values were determined.

**Surface roughness**

The surface roughness test was performed for a total of 21 specimens (7 per material) using a surface roughness meter (DR130, SATOTECH, Kanagawa, Japan). The test specimen was placed with the horizontal surface of the reline, the surface roughness meter was placed vertically, and five measurement points on each specimen were made with an accuracy of ±1 hour each time. The Ra parameter (arithmetic mean roughness) was assessed. The mean Ra value was calculated for each time point and specimen (Excel 2016, Microsoft Office, Microsoft Corporation, Redmond, WA, USA).

**Scanning electron microscopy**

The detailed structures of respective denture relining materials were imaged by SEM (S-3400N; Hitachi, Tokyo, Japan) at an acceleration voltage of 15 kV. Before SEM observation, each relining material sample was cut from the specimens, and palladium vapor deposition was performed. The relining materials were analyzed manually by measuring the relining material surface of 10 randomly selected places. Before undertaking these measurements, the contrast and threshold of each image were optimized to ensure that the surface on the top layers was in focus. The analyses were performed using Adobe Photoshop 5.0 software (Adobe, San Jose, CA, USA).

**Rubber hardness**

Hardness was determined using a Shore A durometer (model GS-709, TECLOCK, Osaka, Japan). This instrument consists of a blunt-pointed indenter attached to a scale by a lever arrangement with a recording scale from 0 to 100 Shore A units. The more the indenter penetrates the specimens, the lower are the hardness values. Five indentations were recorded per specimen under a load of 1 kg and 1 second reading before and after testing. For standardization, the specimens were placed on a glass slab during testing.

**Data analysis**

One-way ANOVA was performed for the retention force, contact angle and surface roughness, and the difference between the averages was compared. After a significant difference was found, Bonferroni’s multiple comparison test was performed for post hoc analysis, and a t-test was performed to assess rubber hardness and compare the differences.

After each item measurement, a multiple regression analysis was used to investigate the effects of contact angle, surface roughness, and rubber hardness on the retention force of the test specimens. Statistical analyses were performed using the IBM SPSS Statistics Package v21 (IBM, Armonk, New York, New York, USA). A P-value of <0.05 was considered statistically significant.

**Results**

**Retention force**

Table 2 shows the mean difference and standard deviation of the retention values for the purified water, 40% glycerin solution and 80% glycerin solution. The soft relining material showed significantly higher holding power than did the conventional relining material.

**Water contact angle**

The mean differences and standard deviations of the contact angles of 80% glycerin aqueous solution, 40% glycerin aqueous solution, and purified water are shown in Table 2. Under all intervening liquid conditions, the conventional relining material was significantly wetter than was the resilient relining materials ($P < 0.05$).
Surface roughness
HR showed the lowest surface roughness, followed by RT-M and RT-S (Table 3). The difference between RT-M and RT-S was not significant, whereas the differences between RT-M and HR and between RT-S and HR, were significant (P < 0.001).

Scanning electron microscopy
SEM showed that the surfaces relined with RT-M, RT-S, and HR were smooth and nearly uniform (Fig. 7). However, the RT-M and RT-S surfaces showed cracks in some places.

Rubber hardness
The mean difference and standard deviation for the rubber hardness values for RT-M and RT-S are presented in Table 3. The RT-M group showed significantly higher rubber hardness than did the RT-S group (P < 0.001). Because the rubber hardness could not be measured in the HR group, these data fields were left blank.

Effect of each measurement item on the retention force
Multiple regression analysis adjusting for type of material and type of intervening liquid revealed a significant association between the retention force and the contact angle (P < 0.001; Table 4). However, surface roughness showed no significant association with the retention force (P = 0.850). Furthermore, types of denture relining material showed no significant association with the retention force (P = 0.078).

Discussion
It has been reported that dentures relined with resilient denture relining material show greater retention than do dentures made of hard material (15). In our in vitro study, there was no significant difference in retention between specimens relined with elastic denture relining material and specimens relined with hard reline material. Because the reason for the difference in the retention force is unclear, this study was designed to investigate the mechanisms underlying the difference in the retention force by measuring the surface morphology (electron microscopy).

Table 2. Measured values of retention force and contact angle.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Retention force (N)</th>
<th>Contact Angle (°)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Mean ± SD</td>
<td></td>
</tr>
<tr>
<td>purified water</td>
<td>HR</td>
<td>7</td>
<td>3.80 ± 0.36</td>
</tr>
<tr>
<td></td>
<td>RT-M</td>
<td>7</td>
<td>30.41 ± 8.51*</td>
</tr>
<tr>
<td></td>
<td>RT-S</td>
<td>7</td>
<td>74.12 ± 10.42*</td>
</tr>
<tr>
<td>40% Glycerin solution</td>
<td>HR</td>
<td>7</td>
<td>5.69 ± 0.35</td>
</tr>
<tr>
<td></td>
<td>RT-M</td>
<td>7</td>
<td>117.60 ± 8.19*</td>
</tr>
<tr>
<td></td>
<td>RT-S</td>
<td>7</td>
<td>115.82 ± 2.96*</td>
</tr>
<tr>
<td>80% Glycerin solution</td>
<td>HR</td>
<td>7</td>
<td>14.15 ± 1.15</td>
</tr>
<tr>
<td></td>
<td>RT-M</td>
<td>7</td>
<td>120.67 ± 6.42*</td>
</tr>
<tr>
<td></td>
<td>RT-S</td>
<td>7</td>
<td>118.77 ± 2.72*</td>
</tr>
</tbody>
</table>

*Significant difference from control (HR) (P < 0.05)

Table 3. Measured values of surface roughness and rubber hardness of the specimen.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Surface Roughness (RA)</th>
<th>viscoelasticity (mN)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Mean ± SD</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>p</td>
<td></td>
</tr>
<tr>
<td>HR</td>
<td>7</td>
<td>1.14 ± 0.21*</td>
<td></td>
</tr>
<tr>
<td>RT-M</td>
<td>7</td>
<td>2.14 ± 0.22*</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>RT-S</td>
<td>7</td>
<td>2.41 ± 0.34</td>
<td></td>
</tr>
</tbody>
</table>

*Significant difference (P < 0.05)
microscopy and surface roughness), wettability (contact angle), and viscosity of the relined specimens. Preparation of the test specimens in this study was meticulously carried out, as any contamination of the studied surfaces would induce an error.

In this study, the rubber hardness of the relining material of the specimen was measured. This was used in determining the categorical variables for the type of resilient denture relining materials. As a result, the rubber hardness of RT-M was significantly higher than that of RT-S. Because HR is a conventional relining material and does not have rubber hardness, it is treated as a missing value in Table 3.

The term “wettability” refers to the ease with which liquid spreads across a solid surface, or more specifically, how the liquid adheres to a solid surface(22). The wettability on the solid surface is measured by the contact angle’s meeting point at the solid-air-liquid, which is a widely known technique. The obtained values depend on the surface tension of the liquid, surface energy of the solid substrate, and surface topography(23, 24). As previously described, a material exhibiting a contact angle greater than 90° is considered hydrophobic, whereas a material with a value smaller than 90° is considered hydrophilic(25). The contact angle can reflect the wettability of denture materials, and it is influenced by many factors, such as surface roughness, surface characteristics, and environmental temperature(26). The attraction of the unlike molecules is termed adhesion, which is one of the essential forces involved in the retention of the denture(27). In order to study the denture retentive force, Stanitz conducted a static experiment using two glass plates, with the retentive force of a denture F given by the expression $F = \frac{2ga}{H}$, where $g$ is the surface tension of the liquid, $a$ is the area between the plates, and $H$ is the thickness of the liquid layer(28). Based on this theory, in clinical application, improving the conformance between the mucosal bearing tissue and the denture, and enlarging the surface area of the denture base as much as possible is important to maximize the retentive force.

In this study, the type of relining material of the specimen and the type of intervened liquid were used as adjusting factors, and the effects of the contact angle of the specimen on the retention force and the surface roughness of the specimen were analyzed using a multiple regression. As a result, it was found that the contact angle of the specimen affected the retention force, and the surface roughness of the specimen did not affect the reten-

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Table 4. Results of multiple regression analysis.

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>Objective variable : retention force</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of denture relining material</td>
<td>0.191</td>
<td>0.078</td>
</tr>
<tr>
<td>Type of intervening liquid</td>
<td>-0.52</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>surface roughness</td>
<td>-0.023</td>
<td>0.85</td>
</tr>
<tr>
<td>water contact angle</td>
<td>0.697</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

$R^2 = 0.846$
tion force. In addition, the retention force increases as the contact angle increases; therefore, the relining material is considered to exhibit a higher retention force when the material is less wet. In the previous report, when determining the force to remove a denture vertically, the contact angle between the denture and saliva increases, as does the force required to remove the denture (29). It is presumed that the viscoelastic properties of the resilient denture relining material affect the fact that the results of this study yielded opposite results. However, details remain unknown and warrant further investigation.

Based on the above findings, the requirements for the relining material for increasing the retention force of the specimens are that they are hydrophobic and the contact angle with the intervening liquid is small. Before and after fabrication of the denture, it is important for the prosthodontist to pay attention to and to know the characteristics of saliva (30).

However, this study remains limited in that in vitro investigations cannot duplicate the clinical situation. Additionally, the purpose of this study was to investigate the relationship between the surface properties and retention force of conventional and resilient denture relining materials. As resilient denture relining materials deform when pressed, the morphological changes may affect the retention force. Thus, future studies must also consider the viscous properties of resilient denture relining materials.

Conclusions
In conclusion, this study demonstrated that the surface roughness of the relining denture material does not affect the retention force of the specimen. In addition, the lesser the wettability of the relining material, the greater the retention force of the specimen.

Acknowledgments
None.

Conflict of Interest
There are no conflicts of interests to declare.

References


