In Vitro Evaluation of Retentive Force of Resilient and Hard Denture Liners

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Abstract

Background

Although the number of people living a long life with natural teeth is increasing due to the rapid growth in the global elderly population, a significant number of elderly people exhibit edentulism. With the onset of a super-aging society, the prolonged lifespan has increased the proportion of the Japanese population that wear dentures.

Complete denture wearers experience problems such as loosening of the denture during speech or mastication. In particular, the problems encountered with complete dentures are contributed to the dentures' problematic retention. Denture retention depends on the thickness of the saliva between the mucosal surface of the denture and the alveolar ridge. Moreover, the amount and viscosity of saliva influence retention.

Although clinicians have reported that silicone-relined mandibular complete dentures show better retention than the complete dentures with a hard denture liner, no research-based evidence is available regarding the retention to the alveolar ridge by using resilient denture liners.

Therefore, this study sought to elucidate the relationship between the retention force and saliva viscosity using a resilient denture liner. As the first step in this research, this in-vitro study aimed to evaluate the retention force of the resilient denture liners compared to hard denture liners by using a simple model.

Materials and Methods

Study I

Tensile tests were performed using a simple model to evaluate retention force of the resilient denture liner compared to hard denture liners. Two kinds of commercially available resilient denture liner (SOFRELINER TOUGH MEDIUM (RT-M)) and (SOFRELINER TOUGH SUPER SOFT (RT-S)), and a hard denture liner (TOKUYAMA REBASE III NORMAL (HR)) used as the control, were examined in the experiment. The retention force was measured for the three denture relining materials under the same conditions using three different intervening liquids for each relining material. The measurements were repeated 10 times for each intervening liquid. The retention force values obtained for different groups and the values of the intervening viscosity of the liquid were compared with the two-way ANOVA. When the results were significant, the Bonferroni test was used as the post-hoc test. The statistical significance was $p < 0.05$.

Study II

Measurements were performed using a simple model to evaluate the retention force, contact angle, and surface roughness of resilient and hard denture liners. Two kinds of commercially available resilient denture liner [SOFRELINER TOUGH MEDIUM (RT-M) and SOFRELINER TOUGH SUPER SOFT (RT-S)] and a hard denture liner [TOKUYAMA REBASE III NORMAL

(HR); control] 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 denture liner. After each item measurement, multiple regression analysis was performed to investigate the effects of the contact angle, surface roughness, and rubber hardness on the retention force of the specimen.

Result

Study I

The results of two-way ANOVA revealed that the saliva viscosity and the denture liner significantly influence denture retention. The Bonferroni multiple comparison test showed that when purified water was used as an intervening liquid, significant differences were observed between all groups, and RT-S showed the highest retention force.

Study II

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

Conclusion

This study concludes that relining a denture with a silicone-based resilient denture liner increases the retention force of the denture. It was particularly effective when the fluid viscosity is high and suggests that the surface roughness of the denture liner does not affect its retention force.

I. Introduction

Japan is known as the super-aging society (1). The Japanese average age population is increasing rapidly, with the proportion of the population over 65 years of age reaching 26.6% in 2015 (2). Although this is the highest proportion in Japanese history, it is expected to further rise to 38.5% by 2065 (3), and the number of elderly people is currently increasing annually. According to reports, 90% of Japanese people receive prosthetic dental treatment, and 88% of elderly people with few remaining teeth need dentures (4). Additionally, the number of denture wearers is increasing with the advent of a super-aged society (5). In particular, complete dentures present problems with retention, stability with eating, difficulty in cleaning, pain, loss of occlusal strength, and poor aesthetics.

Complete denture wearers experience problems such as loosening of the denture during speech or mastication (6) (7) (8) (9). In particular, the problems encountered with complete dentures are contributed to by the problematic retention of the denture (10). Denture retention depends on the thickness of the saliva between the mucosal surface of the denture and the alveolar ridge. Moreover, the amount and viscosity of saliva influence retention (7). For the denture to be retained sufficiently 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 (11) (12) (13). A well-fitted denture mucosal surface and an alveolar ridge are required to establish a thin layer of saliva. However, due to alveolar ridge resorption over time, the denture fit reduce. Then the mucosal surface of the denture is relined using hard polymethyl methacrylate and soft silicone materials.

The application of a resilient denture liner to mandibular complete dentures has been investigated to improve patients' quality of life wearing complete dentures. Several clinical research studies found a significant effect for resilient denture liners that increase the satisfaction rating and chewing ability, as well as reduce sore spots on alveolar ridge mucosa (14) (15) (16). A resilient denture liner acts to absorb and distribute the occlusal forces, thus protecting soft tissues (17), and was also reported to enhance the fitness to the alveolar ridge (18). These effects lead to enhanced denture retention. Although clinicians have reported that silicone-relined mandibular complete dentures show better retention than the complete dentures with a hard denture liner (19), no research-based evidence is available regarding retention alveolar ridge by using resilient denture liners.

Therefore, this study sought to elucidate the relationship between the retention force and saliva viscosity using a resilient denture liner (study I). The successive study examined the surface properties of three types of denture liners using scanning electron microscopy (SEM), determine their surface roughness and wettability, and identify the factors that affect the retention force of the material. (Study II). As the first step in this research, this in-vitro study aimed to evaluate retention force of the resilient denture liner compared to hard denture liners by using a simple model.

II. Materials, Methods and Results

1. In vitro evaluation of resilient liner and conventional liner on the retentive force. (Study I)

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. Two commercially available resilient denture lining materials, one has low rubber hardness (SOFRELINER TOUGH MEDIUM, Tokuyama, Tokyo, Japan (RT-M)) compared to (SOFRELINER TOUGH SUPER SOFT, Tokuyama, Tokyo, Japan (RT-S)). A hard denture liner (TOKUYAMA REBASE III NORMAL, Tokuyama, Tokyo, Japan, (HR)) as the control was used in the experiments.

1) Measurement of retention force

1.1) Fabrication of specimen: simulated denture

The specimens were fabricated as disks with an acrylic resin base. One side of the specimen was relined with a denture liner, and the other side was fitted with a hook applying device to measure the retention force. The area of the relined surface of the specimen was set to a value close to the area of the support of the lower denture, 14 cm^2 on average (20). The diameter of the relined surface was 50 mm, and the thickness of the denture liner was 2 mm, according to the instructions of the manufacturer. The fabrication process is illustrated in Figure 1. First, we made resin blocks for lathe processing. Columnar paraffin wax with a diameter of 75 mm and a height of 60 mm was fabricated and invested in a metal flask (Flask Upper, Whip Mix Co., Kentucky, USA) with gypsum (Dental Plaster, Mutsumi, Mie, Japan). The invested paraffin wax was lost by running hot water and injected with a heat-curable acrylic resin. The acrylic resin was slowly heat-polymerized in a heat polymerizer (Aqua Marathon, Dentronics, Tokyo, Japan).

The base resin was carved out from a resin block (Figure 2 A). Numerical Control (NC) machine tools (SP-CHP, Shizuoka Iron Works, Shizuoka, Japan) and NC lathes (SL-25, DMG MORI CO., LTD., Nagoya, Japan) were used for lathe machining. The denture base resin was machined in the form of a cylinder with a diameter of 50 mm and a height of 8 mm. The opposite side of the relined surface was fitted to a cylindrical box, a diameter of 65 mm and a height of 5 mm (Figure 1 vi, Figure 2 A). A stainless-steel eyebolt (IB-4M, Mizumoto Machine Mfg. Co., Ltd., Hyogo, Japan) was attached to the center of the box tray with an M4 screw hole (Figure 2 B). A part of the stainless-steel eyebolt was processed into a form for attaching the traction line. The denture base resin was divided into three groups, with each material constituting a group, and eight pieces were fabricated for each group.

The spacing box was obtained by lathe fabricating from a polytetrafluoroethylene (PTFE) block (Teflon, DuPont, Delaware, USA) and had a pipe shape with an outer diameter of 70 mm, an inner diameter of 50 mm, and a height of 10 mm (Figure 2 C). The base resin side of the box was provided with a groove with a height of 3 mm for opening the box. By fitting the base resin and the spacing box, space was provided on the reline surface for relining with a thickness of 2 mm (Figure 1 vii).

Next, the denture liner was injected. The surface treatment associated with the denture liner injecting operation, adhesive application, and the adjustment of the denture liner were in accordance with the instructions of the manufacturer. After treating the surface of the base resin with a primer (SOFRELINER TOUGH PRIMER, Tokuyama, Tokyo, Japan), the base resin and the spacing box were fitted together, and the resilient denture liner was injected (Figure 1 viii, Figure 2 D). Similarly, for the hard denture liner injection, 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). Then, after waiting for 30 minutes at room temperature to confirm polymerization, the completed specimens were carefully removed from the spacing box (Figure 1 ix, Figures 2 E, F). The specimens were fabricated at room temperature of 23 ± 2 ° C and relative humidity of 50 ± 10%.

1.2) Fabrication of specimen: simulated mucosal

A plate made of PTFE (diameter of 70 mm, the thickness of 10 mm) was fabricated by lathing as a part corresponding to the simulated mucosa (Figure 3 A). The surface of the PTFE plate was first mechanically polished and then finally polished with water-resistant paper (EA366C - 200, ESCO, Osaka, Japan) with a grain size of #2000. Protrusions (50mm × 20 mm× 10mm) for fixing were attached to the opposite side of the PTFE plate and fixed with screws (Figure 3 B).

1.3) Preparation of 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. Simulated intervene liquid was produced with 40 and 80% glycerin aqueous solution (high viscosity) by assuming viscosity of the human saliva (21). Also, purified water (Kenei Pharmaceutical Co., Ltd., Osaka, Japan) without glycerin was used as control. A tensile test was performed with each intervening liquid interposed.

1.4) Tensile test

A universal tensile compression tester (Techno Graph TG-5kN, MinebeaMitsumi, Nagano, Japan) was used for the tensile test. It was reported that the cohesive force of the intervening simulated saliva is maximized when the distance between the denture base and the oral mucosa is minimal, obtaining the highest retention force of the denture base (11). 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 (1.0 mL) was gently dropped into the center of the PTFE plate using a micropipette relined surface of the specimens was gently placed on the PTFE plate.

The average occlusal force of complete denture wearers were 3.4 kgf (22). To simplify the operation and to prevent non-vertical forces from being applied when removing the load on the experiment, when the load was set to 2 kgf, and the preliminary experiment was performed, the load holding time was set to 10 seconds, and then, 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 (Figure 4).

The crosshead speed (CHS) of the universal tester was set to 10 mm/min, and the retention force required to vertically separate the specimens was measured. The obtained values were divided by the area of the bottom surface of the specimen to obtain the retention force per unit area.

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

2) Measurement intervening liquid viscosity

After the intervening liquid was fabricated, the viscosity of the intervening liquid was measured using a vibrating viscometer (Viscomate VM-10A, SEKONIC, Tokyo, Japan). The intervening liquid was prepared at room temperature of 23 ± 2 °C and relative humidity of 50 ±10%.

3) Statistical analyses.

We used the two-way analysis of variance (ANOVA) to determine the effect of denture liner and the viscosity of the intervening liquid on retention force interaction. When interactions were observed, post hoc Bonferroni tests were used to compare the retention force among denture liner and the viscosities of the intervening liquids, and the main effects were compared. All statistical analyses were performed using the IBM SPSS Statistics Package v21 (IBM, Armonk, New York, USA). The statistical significance was $p < 0.05$.

4) Results

We evaluated the difference in retention force between the resilient denture liners and the hard denture liner. After the difference in retention force was confirmed, it was evaluated whether the interaction between different denture liners and different intervening liquid viscosities affected the retention force. The viscosity of the intervening liquid was 22.4 mPa · s with 80% glycerin aqueous solution, 14.1 mPa · s with 40% glycerin aqueous solution, and 1 mPa · s with purified water. Significant main effects were observed for each factor of the type of denture liner and the type of intervening liquid ($p < .001$). As shown in Figure 5, there was a significant interaction between the effect of the denture liner and the viscosity of the intervening liquid on the retention force ($p < .001$). The RT-M and RT-S retention force showed significantly higher retention force when the 80% and 40% glycerin aqueous solutions were intervened compared to when the purified water was intervened ($p < .001$). On the other hand, the HR showed significantly higher retention force when the 80% glycerin aqueous solution was intervened compared to when the 40% glycerin aqueous solution and the purified water were intervened ($p = 0.041, 0.01$). When comparing the denture liner, there was a significant difference between all groups when purified water was intervened, and RT-S showed the highest retention force ($p < 0.01$). On the other hand, when 80% glycerin aqueous solution and 40% glycerin aqueous solution were intervened, RT-M and RT-S showed significantly higher retention force than HR ($p < 0.01$).

2. In Vitro Evaluation of the Relationship Between the Surface Properties and Retention Force of Resilient Liners and Conventional Liners (Study II)

Similar to Study 1, specimens were fabricated, simulated mucosa was prepared, intervening fluid was prepared, and the retention force was measured. After that, the wettability, surface roughness, and surface structure of the denture liner were observed, and the rubber hardness was measured.

1) Water contact angle

The water contact angle was measured using a contact angle meter (CA-DT, Kyowa Interface Science Co. Kagawa. Japan). 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.

2) 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 relining surface of the specimen horizontally, 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 mean Ra value was calculated for each time point and specimen.

3) Scanning electron microscopy

The detailed structures of respective denture liners were imaged by SEM (S-3400N; Hitachi, Tokyo, Japan) at an acceleration voltage of 15 kV. Before SEM observation, each denture liner sample was cut from the specimens, and palladium vapor deposition was performed. The denture liners were analyzed manually by measuring the denture liner surface of 10 randomly selected places. Before undertaking these measurements, contrast of each image and threshold 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).

4) 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 1 kgf and 1 second reading load before and after testing. For standardization, the specimens were placed on a glass slab during testing.

5) Data analysis

One-way ANOVA was performed for the retention force, contact angle, and surface roughness, and the difference between the average was compared. After a significant difference was found, Bonferroni's multiple comparison test was performed for post hoc analysis. And we performed a t-test assessing rubber hardness and compared 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.

6) Result

6.1) 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 resilient denture liner showed significantly higher Retention force than did the hard denture liner.

6.2) 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 hard denture liner was significantly wetter than was the resilient denture liner ($P < 0.05$).

6.3) Surface roughness

HR showed the lowest surface roughness, followed by RT-M and RT-S in 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 highly significant.

6.4) Scanning electron microscopy

SEM showed that the surfaces relined with RT-M, RT-S, and HR were smooth and nearly uniform (Figure 6). However, the RT-M and RT-S surfaces showed cracks in some places.

6.5) 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.

6.6) Effect of each measurement item on the retention force

Multiple regression analysis with the type of material and the type of intervening liquid as adjusting factors revealed a significant association between the retention force and the contact angle ($P < 0.001$; Table 4). However, the surface roughness showed no significant association with the retention force ($P = 0.850$). Also, Types of denture liner showed no significant association with the retention force ($P = 0.078$)

III. Discussion

The study I hypothesis was no difference in retention force between denture liner under the same intervening liquid, and no interaction with the materials and intervening liquid on the retention force. In this fundamental in vitro study, simple-designed relined test specimens were used to evaluate retention force under different intervening liquids of different viscosities simulated as saliva. In theory, the retentive force is affected by physical properties of the saliva and the thickness of the salivary layer. The denture base area covering the alveolar ridge mucosa is also an influencing factor (23). Thus, this study used three types of intervening liquids, low, mid, and high viscosities, to simulate three intraoral salivary conditions. Combining intervening liquids and simple-designed relined test specimens had led to maintain a standardized in-vitro experimental system.

The result indicated that two resilient denture liner showed significantly higher retentive force than the hard denture liner within the respective intervening liquids. There was an increasing tendency of the retention force in all the denture liners by increasing the viscosity of the intervening liquid. Based on the theoretical proposal, this result of the study seems valid since the retention force increases according to the viscosity of the intervening liquid (23).

The Resilient denture liner showed a significantly higher retention force than the HR at viscosity of the three types of intervening liquid. The result indicates that the specimen relined with the resilient denture liner exhibits high retention than the hard denture liner. It is noteworthy that RT-M and RT-S were significantly different under the purified water. However, the difference has turned to no significant difference under 40% and 80% solutions. This result indicates that when the viscosity of the solution increases, the interaction of the materials and intervening solution occurs, and the material character difference of RT-M may be compensated and get close to RT-S. However, this assumption and mechanism remain unclear. With the difference between the resilient and hard denture liner, the former has significant elastic deformation and elastic recovery properties than the latter (24). Moreover, in this experiment, resilient denture liner was pressured against the PTFE plate. The silicone deformed elastically and generated negative pressure at the interface of the plate than the hard denture liner.

The interaction mechanism, the phenomenon of retention of RT-M and RT-S at 40% and 80% solutions, is also interesting. However, the mechanism is unclear. Assuming viscosity of the intervening liquid plays an important role, why the interaction occurs only with RT-M and RT-S at 40% remains unclear. The precise testing of the materials, for example, examining the creep behavior, may suggest some phenomenon mechanism. It is also assumed that the difference in the wettability may affect the retentive force. The measurement of the contact angle of the respective denture liners should be assessed to consider in detail.

Therefore, study II was designed to investigate the mechanisms underlying the difference of the retention force by measuring the surface morphology (electron 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 be expected to induce an error.

In this study, the rubber hardness of the denture liner of the specimen was measured. This was used in determining the categorical variables for the type of resilient denture liner. As a result, the rubber hardness of RT-M was significantly higher than that of RT-S. Because HR is a hard denture liner 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 (25). The meeting point of the contact angle measures the wettability of the solid surface at the solid-air-liquid, which is a widely known technique. The obtained values depend on the surface tension of the liquid, the surface energy of the solid substrate, and surface topography (25). As previously described, a material exhibiting a contact angle greater than 90° is considered hydrophobic, while a material with a value smaller than 90° is considered hydrophilic (26). The contact angle can reflect wettability of the denture materials, and it is influenced by many factors, such as surface roughness, surface characteristics, and environmental temperature (27). The attraction of the unlike molecules is termed adhesion, which is one of the essential forces involved in retaining the denture (28). 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 $F = 2ga/H$, 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 (29). 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 denture liner 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 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 retention force. Also, the retention force increases as the contact angle increases; therefore, the denture liner 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 denture and contact angle of the saliva increases, as does the force required to remove the denture (30). It is presumed that the viscoelastic properties of the resilient denture liner 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 denture liner 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 the denture fabrication, it is important to know the characteristics of saliva and imperative for the prosthodontist to pay attention (31).

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 liner. As resilient denture liner deform when pressed, the morphological changes may affect the retention force. Thus, future studies must also consider the viscoelastic properties of resilient denture liner.

IV. Conclusions

1. The interaction between the type of denture liner and viscosity of the intervening liquid demonstrated that resilient liners with low viscosity should be chosen carefully to gain an adequate retentive force.
2. When the viscosity of the intervening liquid was low, it was found that low resilience silicone gained higher retention force than high resilience materials.
3. Using resilient denture liner may provide a higher retention force than using the hard denture liner in the high viscosity of the intervening liquid.
4. This study demonstrated that the surface roughness of the denture liner does not affect the retention force of the specimen.
5. It was indicated that the resilient denture liners have high retention force (to simulated mucosal) although they have poor wettability in comparison with hard denture liners.

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VI. Table and Figures

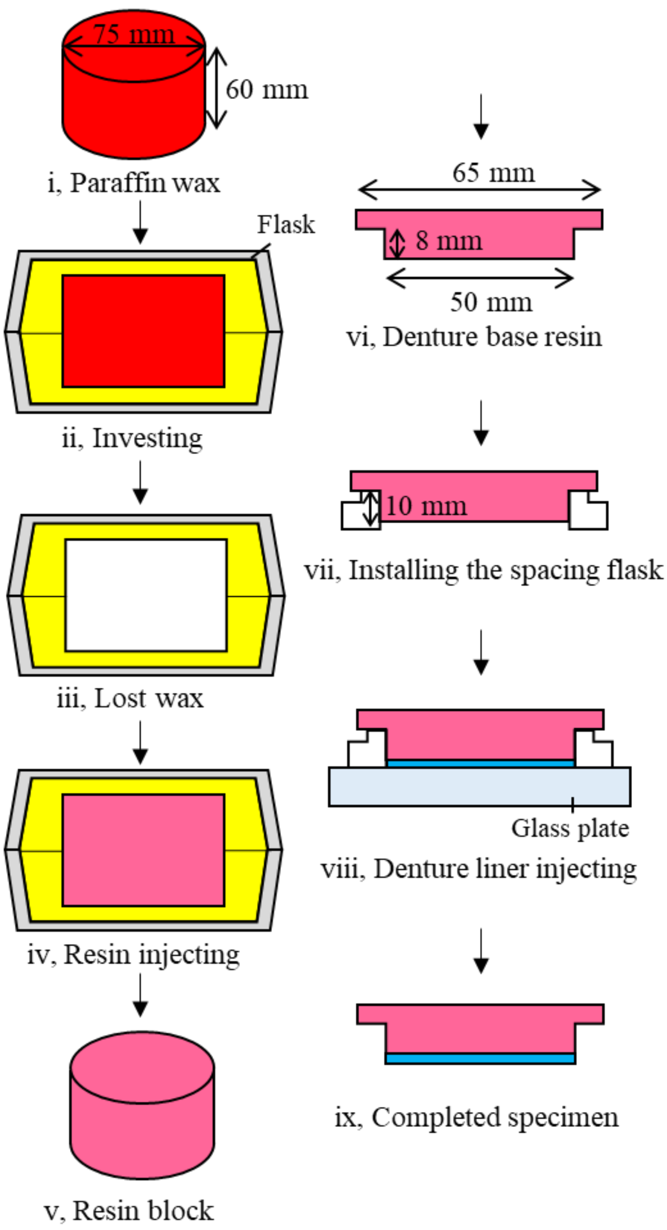

Figure 1. Specimen fabricating method.

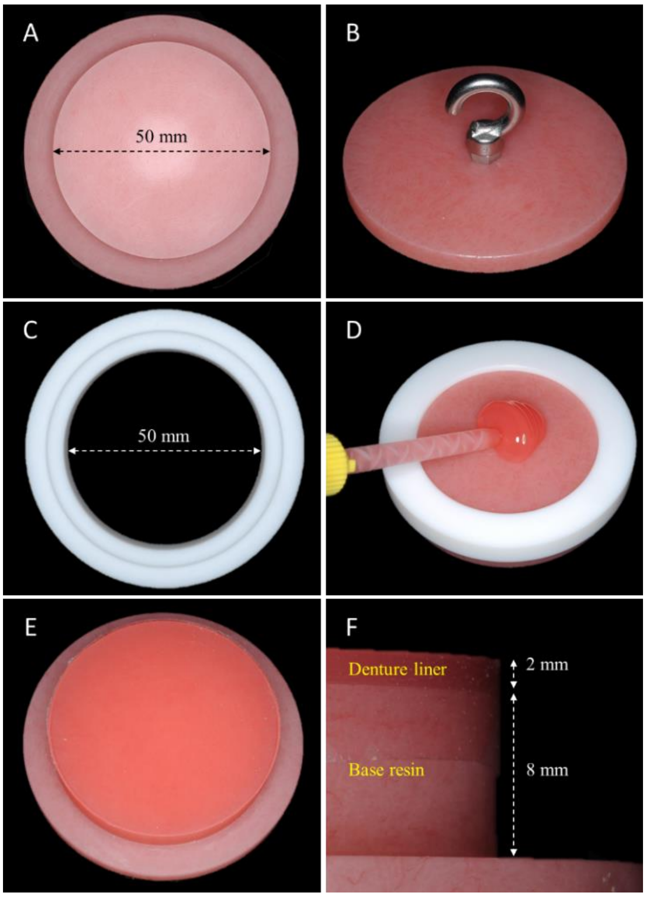

Figure 2. (A) The diameter of the relining surface of the fabricated base resin is 50 mm. (B) A stainless-steel eyebolt was attached to the center of the box tray with an M4 screw hole. (C) The spacing box was obtained by lathe fabricating from a PTFE block. It had a pipe shape with an outer diameter of 70 mm, an inner diameter of 50 mm, and a height of 10 mm. (D) Injecting denture liner. (E) The diameter of the fabricated specimen's relining surface is 50 mm. (F) The thickness of the denture liner is 2 mm.

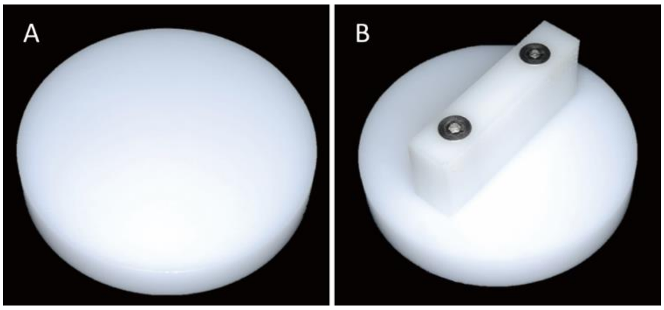

Figure 3. (A) A plate made of PTFE (diameter of 70 mm, the thickness of 10 mm) was fabricated by lathing as a part corresponding to the simulated mucosa. (B) Protrusions (50mm × 20 mm× 10mm) for fixing were attached to the opposite side of the PTFE plate and fixed with screws.

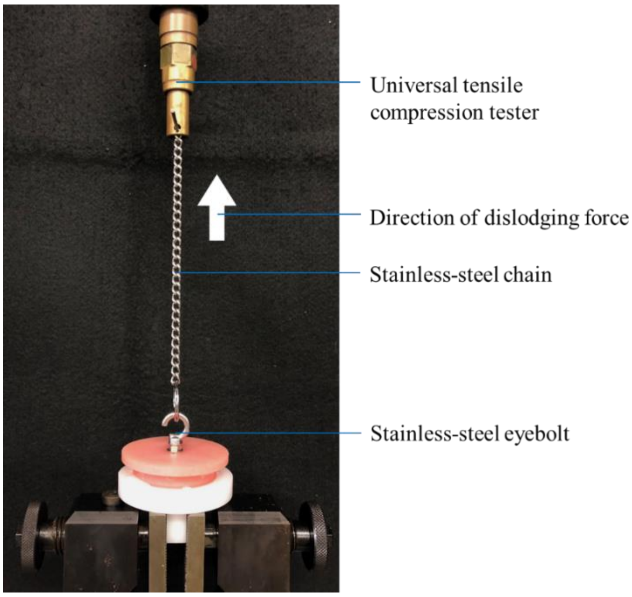

Figure 4. A tensile test was performed using a universal tensile compression tester.

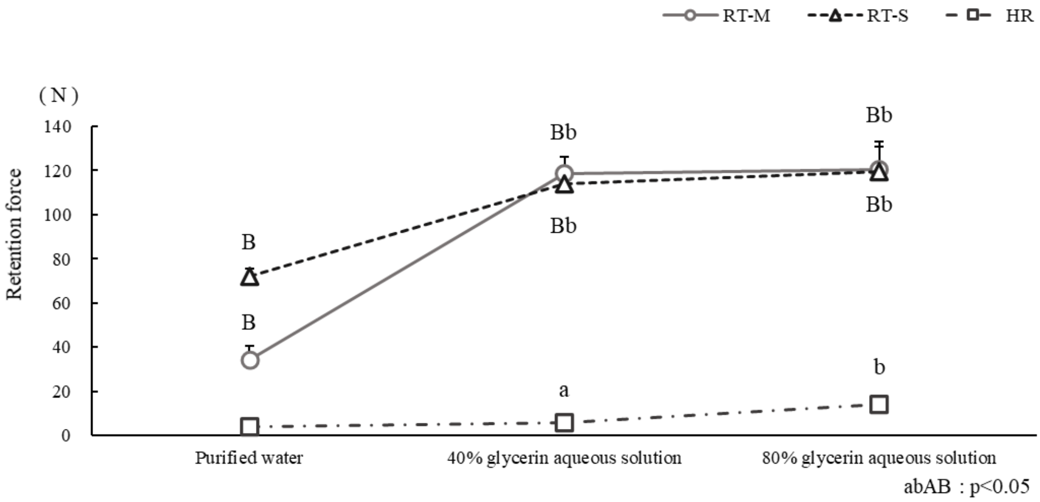

Figure 5. Comparison of retention force. As a result of the test of the simple main effect, RT-M and RT-S showed significantly higher retention force when 80% and 40% glycerin aqueous solution was intervened than when purified water. HR showed significantly higher retention force when 80% glycerin aqueous solution was intervened than when the 40% glycerin aqueous solution and purified water. (HR; TOKUYAMA REBASE III NORMAL, RT-M; SOFRELINER TOUGH MEDIUM, RT-S; SOFRELINER TOUGH SUPER SOFT)

A: No Significant difference compared to HR.

B: Significant difference compared to HR.

a: No Significant difference compared to purified water.

b: Significant difference compared to purified water.

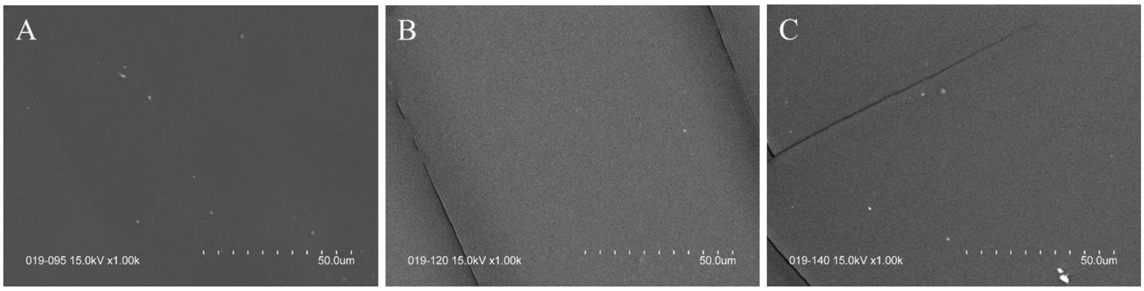

Figure 6. scanning electron microscopy (SEM) images of the surface of the denture liner. All images were taken at 1000 magnification (A: HR, B: RT-M, C: RT-S).

Table 1. Materials used in this study. (RT-M; SOFRELINER TOUGH MEDIUM, RT-S; SOFRELINER TOUGH SUPER SOFT, HR; TOKUYAMA REBASE III NORMAL)

Materials				
Brand name	Code	Materials type	Curing type	Lot no. (powder/liquid)
URBAN		Denture base material	Heating polymerization	021961/021729
TOKUYAMA REBASE Ⅲ NORMAL	HR	Hard denture lining material	Autopolymerization	028097
SOFRELINER TOUGH MEDIUM	RT-M	Resilient denture lining material	Autopolymerization	088037P
SOFRELINER TOUGH SUPER SOFT	RT-S	Resilient denture lining material	Autopolymerization	1290Y8P

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

		N	Retention force (N)		Contact angle (°)	
			Mean ± SD	*p*	Mean ± SD	*p*
Purified water	HR	7	3.80 ± 0.36		81.54 ± 0.96	
	RT-M	7	30.41 ± 8.51*	< 0.001	105.23 ± 0.67*	< 0.001
	RT-S	7	74.12 ± 10.42*		106.09 ± 0.72*	
40% Glycerin solution	HR	7	5.69 ± 0.35		80.00 ± 0.35	
	RT-M	7	117.60 ± 8.19*	< 0.001	103.46 ± 0.54*	< 0.001
	RT-S	7	115.82 ± 2.96*		104.03 ± 1.15*	
80% Glycerin solution	HR	7	14.15 ± 1.15		76.94 ± 1.25	
	RT-M	7	120.67 ± 6.42*	< 0.001	100.06 ± 0.56*	< 0.001
	RT-S	7	118.77 ± 2.72*		100.63 ± 0.38*	

*Significant difference from control (HR) ($p < 0.05$)

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

	N	Surface roughness (RA)	*p*	Rubber hardness (mN)	*p*
		Mean ± SD		Mean ± SD	
HR	7	1.14 ± 0.21 ┐* (vs RT-M) ┐* (vs RT-S)	< 0.001	N.D.	
RT-M	7	2.14 ± 0.22 ┘		52.93 ± 0.90 ┐*	0.006
RT-S	7	2.41 ± 0.34 ┘		46.08 ± 4.99 ┘	

*Significant difference ($p < 0.05$)

(N.D.: Not Detected)

Table 4. Results of multiple regression analysis.

Explanatory variable	Objective variable : Retention force	
	Partial regression coefficient	*p*
Types of denture liner	0.191	0.078
Type of intervening liquid	-0.52	< 0.001
Surface roughness	-0.023	0.85
Water contact angle	0.697	< 0.001
	$R^2 = 0.846$	

Significant difference ($p < 0.05$)