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Effect of mechanical and chemical cleaning on surface roughness of silicone soft relining material

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Abstract
Purpose
This study aims to investigate the effect of mechanical and chemical cleaning on the surface roughness of silicone soft relining materials.

Methods
We selected silicone soft relining materials with the highest (Soft) and lowest (Supersoft) Shore A hardness. In the abrasion test, specimens were cleaned 50,000 times using a kitchen sponge (Sponge), a soft (Soft brush) or hard (Hard brush) denture brush, or stored in water (No cleaning). In the immersion test, specimens were immersed in either water (Water), neutral peroxide denture cleanser (Neutral), alkaline peroxide denture cleanser (Alkaline), or hypochlorite denture cleanser (Hypochlorite) for 1440 h. Surface roughness of the arithmetic mean height of the surface (Sa) and maximum height (Sz) were measured before and after the tests. Data were analyzed using the Kruskal–Wallis and Mann–Whitney U tests.

Results
In the abrasion test, significant differences were observed for Sa and Sz with Soft relining materials, but not for No cleaning and Sponge. In the immersion test, significant differences were observed for Sa and Sz with Soft relining materials, but not between Water and Neutral or Water and Alkaline. Significant differences were observed with Supersoft, except between Water and Neutral or Water and Alkaline for Sa and between Water and Neutral for Sz.

Conclusions
Mechanical cleaning using a sponge did not increase the surface roughness of the material with a high Shore A hardness. Furthermore, neutral peroxide denture cleanser did not increase the roughness of
materials with high and low Shore A hardness.

**Keywords:** Soft relining material; Mechanical cleaning; Chemical cleaning; Removable denture; Surface roughness

# 1 Introduction

The thinning of denture underlying tissue, ridge of alveolar bone after tooth extraction, and large bite force may cause pain and may not improve even if removable dentures are adjusted. In these cases, relining of the denture with soft relining material (soft relining) is effective in reducing pain [1]. Acrylic and silicone are two commonly used types of soft relining materials. Even though acrylic soft relining material has a greater cushioning effect than silicone soft relining material owing to its viscoelasticity [2], the plasticizer is eluted over time after polymerization, resulting in an increase in hardness [3]. Conversely, the hardness of the silicone soft relining material is relatively stable owing to its stable siloxane polymer and has long-lasting cushioning effects [4]. Therefore, silicone is the first choice in soft relining material. Fungi have been shown to readily adhere to soft relining materials compared to hard acrylic resin [5]. Furthermore, an increase in fungi attached to the removable denture was associated with an increased risk of denture stomatitis and aspiration pneumonia [6,7]. Therefore, effective cleaning of the soft relined denture is essential.

Mechanical cleaning involves the use of a denture brush, whereas chemical involves the use of a denture cleanser for cleaning removable dentures. Mechanical cleaning physically removes the biofilm on the denture [8], whereas chemical cleaning sterilizes the denture by dissolving bacterial and fungal proteins using ions [9]. Combining mechanical and chemical cleaning is recommended because it yields better results than those yielded by one method alone and reduces the amount of bacteria and fungi attached to the denture [10]. In a previous report, mechanical cleaning that involved the use of a denture brush for the soft denture base resulted in roughness of the silicone soft relining material surface [11], which can lead to increased fungal attachment [12]. Dentists may instruct the patients to opt for chemical cleaning alone for cleaning silicone soft relining material to avoid the increase in surface roughness caused by mechanical cleaning [13]. Therefore, for achieving more effective cleaning, it is important to identify a mechanical cleaning method that causes roughening of the soft relining material surface.

Denture brushes with bristles with a larger diameter have greater stiffness [14]. Classification of tooth and denture brushes according to brush stiffness was defined by the International Organization for Standardization (ISO) [15]. Usually, denture brushes have high stiffness and are classified as “hard,” whereas those for dentures with soft relining materials have lower stiffness and are classified as “soft.” Cleaning silicone soft relining materials with these brushes caused roughening of the silicone soft relining material surface. However, the roughness was reduced with the use of a denture brush with lower stiffness [11]. We hypothesized that the surface roughness of dentures with silicone soft
relining materials will not change after mechanical cleaning of the soft denture base using a sponge, which has lower stiffness than a denture brush.

Denture cleansers are categorized as acidic, neutral, weak alkaline, or strong alkaline. Neutral and alkaline denture cleansers are commercially available as tablets and are used in home care. Denture cleansers are classified as enzymatic, peroxide, or hypochlorite based on their ingredients. Although hypochlorite denture cleaners have greater sterilization effects owing to their high oxidative power compared with alkaline peroxide denture cleansers [16], hypochlorite denture cleaners increase the roughness of acrylic resin [17]. Additionally, cleaning the soft relining material with peroxide and alkaline denture cleaner increases the roughness of the surface [18], whereas cleaning with neutral peroxide denture cleaners does not increase the roughness of the surface even after immersion for 4 months [11]. Therefore, our second hypothesis was that a neutral peroxide denture cleanser can clean dentures with silicone soft relining material without roughening the surface.

The current study investigated the effects of mechanical cleaning using a denture brush and sponge and chemical cleaning using a denture cleanser on the surface roughness of a silicone soft relining material and aimed to identify a cleaning method that does not roughen the soft relining surface. The null hypotheses are that there is no difference in surface roughness after mechanical cleaning between sponge or denture brush and there is no difference in surface roughness after immersion among the types of denture cleansers.

2 Materials and methods

2.1 Silicone soft relining material

Shore A hardness, adhesion strength, water absorbability, and solubility of the silicone soft relining material were defined by ISO [19]. We focused on Shore A hardness, which was believed to be responsible for abrasion resistance of silicone soft relining materials. Two types of silicone soft relining materials were selected: GC Reline II Soft (GC Corp., Tokyo, Japan) (Soft), which had the highest Shore A hardness (48.8) and Sofreliner Supersoft (Tokuyama Dental Corp., Tokyo, Japan) (Supersoft), which had the lowest Shore A hardness (8.0), according to a report by Kubo et al. [20].

2.2 Specimens

A 2-mm-thick plate-shaped heat-curing denture base acrylic resin (Acron No. 8; GC Corp.) and a 2-mm-thick acrylic plate were laminated and temporarily fixed in paraffin wax. Subsequently, this was invested with a flask, and the temporary fixed acrylic plate was removed after the plaster hardened. A primer was applied to the denture base acrylic resin surface in the flask and dried. Then, the silicone soft relining material was filled and left standing for 30 min while pressurizing with a force of 392 N. The denture base acrylic resin with the silicone soft relining material was removed from the flask and
cut to a size of 10 × 20 mm; excess silicone soft relining material was removed. The silicone soft relining material specimens with large bubbles and scratches on the surface were excluded. This was used as the specimen and was cleaned using an ultrasonic cleaner (Aiwa Ultrasonic Cleaner AU-80C; Aiwa Medical Industry, Tokyo, Japan) in water for 10 min to remove the plaster attached to the surface. After ultrasonic cleaning, the specimens were not surface treated.

2.3 Abrasion test

Specimens were cleaned using a kitchen sponge (Scotch-Brite; 3M, St. Paul, MN, USA), a hard denture brush (Ci Denture Brush; Ci Medical Co., Kanazawa, Japan), or soft denture brush (Ci Denture Brush S; Ci Medical Co.) to evaluate the effects of mechanical cleaning on the surface roughness of the silicone soft relining material. The specimens were categorized into four study groups: specimens stored in water (No cleaning), specimens cleaned using a kitchen sponge (Sponge), specimens cleaned using a soft denture brush (Soft brush), and specimens cleaned using a hard denture brush (Hard brush). No cleaning specimens were used as negative controls, whereas the Hard brush specimens were used as positive controls.

The abrasion test was performed using a toothbrush abrasion tester (K236; Tokyo Giken Inc., Tokyo, Japan), which was applied at a test speed of 150 times/min with a stroke width of 30 mm, in which a 2.9-N load in water at room temperature of 25 °C ± 2 °C. To simulate cleaning four times a day for 30 s over a 6-month period, the repeat count was set to 50,000, as described previously by Amano et al. [21]. The specimens were washed with a sponge or denture brush in the direction parallel to the short side. No cleaning specimens were immersed in water for the same amount of time as the cleaning time (333 min). There were five specimens included in each study group (40 in total).

2.4 Immersion test

The specimens were immersed in water at a temperature of 25 °C ± 2 °C, in either tap water (Water), enzyme plus neutral peroxide denture cleanser (Neutral; Porident; Glaxo Smith Kline, London, UK), enzyme plus alkaline peroxide denture cleanser (Alkaline; Butler Denturecleaner; Sunstar, Osaka, Japan), or 0.5% (w/v) hypochlorite denture cleanser (Hypochlorite; Labalak D; Sundental Corp., Osaka, Japan) for 1440 h to simulate approximately 6 months (8 h per day) of immersion. Every 8 h, the immersion fluid was changed. The hypochlorite denture cleanser has strong oxidizing properties and was previously reported to have caused roughness of the acrylic resin surface [22] as well as discoloration of the silicone soft relining material surface [23]. Hence, immersion in the hypochlorite denture cleanser was used as the positive control, and immersion in water as the negative control. There were five specimens in each study group (40 in total).

2.5 Surface roughness
Surface roughness was measured using three-dimensional laser microscopy (LEXT OLS4000; Olympus, Tokyo, Japan) with a measurement range of 1280 µm × 1280 µm, magnification of 10×, and a cutoff value of 250 µm for the wavelength removed from the profile curve. The arithmetic mean height of the surface (Sa) and maximum height (Sz) were measured at five points from the center of the specimens for each specimen, and the mean was calculated. Measurements were obtained before and after the abrasion and immersion tests were performed.

The surface morphology of the soft relining material was observed using a three-dimensional analytical scanning electron microscope (ERA-8900FE; Elionix Inc., Tokyo, Japan) with a measurement range of 1800 µm × 2400 µm and magnification of 50× in the abrasion tests and measurement range of 180 µm × 240 µm and magnification of 500× in the immersion tests. Observations were recorded after the abrasion and immersion tests were performed.

2.6 Statistical analysis

Sa and Sz were analyzed using the Kruskal–Wallis test, followed by the Mann–Whitney U test for the abrasion and immersion tests. The significance level was set to 0.05. For multiple comparisons, Bonferroni correction was performed. The software used in this study was statistical software (SPSS version 22, International Business Machines Corp., Chicago, IL, USA).

3 Results

3.1 Abrasion test

Figs. 1 and 2 present the results of the abrasion test. Except in the Sponge and No cleaning groups, significant differences were observed for both Sa and Sz in the Soft group. In the Supersoft group, there were significant differences among all the groups for both Sa and Sz. Figs. 3 and 4 present the observation results for the soft relining material surface after the abrasion test. In Soft, the surface roughness of sponge was recognized to be the same as No cleaning, while Soft brush and Hard brush were found more rough than No cleaning (Fig. 3). With Supersoft, Sponge, Soft brush, Hard brush were found more rough than No cleaning (Fig. 4).
Fig. 1 Comparison of surface roughness among No cleaning, Sponge, Soft brush, and Hard brush groups after the abrasion test in Soft. (A) Arithmetic mean height (Sa), (B) maximum height (Sz). N = 5, *P < 0.05.
Fig. 2 Comparison of surface roughness among No cleaning, Sponge, Soft brush, and Hard brush groups after the abrasion test in Supersoft. (A) Arithmetic mean height (Sa), (B) maximum height (Sz). N = 5, *P < 0.05.
Fig. 3 Surface observation of the Soft group after the abrasion test. The specimens are scanned at 50 × magnification. The measurement area is 1800 µm × 2400 µm. (A) No cleaning, (B) Sponge, (C) Soft brush, and (D) Hard brush.

Fig. 4 Surface observation of the Supersoft group after the abrasion test. The specimens are scanned at 50 × magnification. The measurement area is 1800 µm × 2400 µm. (A) No cleaning, (B) Sponge, (C) Soft brush, and (D) Hard brush.
3.2 Immersion test

Figs. 5 and 6 present the results for the immersion test. In the Soft group, significant differences were observed, except between Water and Neutral and Water and Alkaline for Sa as well as Sz. In the Supersoft group, significant differences were observed, except between Water and Neutral and Water and Alkaline for Sa and between Water and Neutral for Sz. Figs. 7 and 8 show the surface observation results after the immersion test. In the Soft group, the surface roughness of Neutral and Alkaline were recognized to be the same as Water, and Hypochlorite was more rough than Water (Fig. 7). In the Supersoft group, the surface roughness of Neutral was recognized to be the same as Water, and Alkaline and Hypochlorite were more rough than Water (Fig. 8).
Fig. 5 Comparison of surface roughness among Water, Neutral, Alkaline, and Hypochlorite groups after the immersion test in Soft. (A) Arithmetic mean height (Sa), (B) maximum height (Sz). $N = 5$, $^*P < 0.05$. Water: tap water, Neutral: enzyme plus neutral peroxide denture cleanser, Alkaline: enzyme plus alkaline peroxide denture cleanser, and Hypochlorite: hypochlorite denture cleanser.
Fig. 6 Comparison of surface roughness among Water, Neutral, Alkaline, and Hypochlorite groups after the immersion test in Supersoft. (A) Arithmetic mean height (Sa), (B) maximum height (Sz). $N = 5$, *$P < 0.05$. Water: tap water, Neutral: enzyme plus neutral peroxide denture cleanser, Alkaline: enzyme plus alkaline peroxide denture cleanser, and Hypochlorite: hypochlorite denture cleanser.
Fig. 7 Surface observation of the Soft group after the immersion test. The specimens are scanned at 500 × magnification. The measurement area is 180 µm × 240 µm. (A) Tap water, (B) neutral peroxide denture cleanser, (C) alkaline peroxide denture cleanser, and (D) hypochlorite denture cleanser.

Fig. 8 Surface observation of the Supersoft group after the immersion test. The specimens are scanned at 500 × magnification. The measurement area is 180 µm × 240 µm. (A) Tap water, (B) neutral peroxide denture cleanser, (C) alkaline peroxide denture cleanser, and (D) hypochlorite denture cleanser.

4 Discussion
In the Soft group with high Shore A hardness, Sa and Sz increased following cleaning in the Hard brush and Soft brush groups but did not change in the Sponge group. In the Supersoft group with low Shore A hardness, Sa and Sz increased after cleaning in the Hard brush, Soft brush, and Sponge groups. The presence of many cross-linked structures increases the hardness of organic materials [24]. For the silicone soft relining material used in this study, the tensile strength was 3.85 MPa for Soft and 1.06 MPa for Supersoft [20]. It is considered that the density of the cross-linked structures is associated with the difference between Shore A hardness and tensile stress of the two materials. Therefore, the surface structure was not destroyed by the sponge in the Soft group because the dense cross-linked structures prevented the formation of a rough surface. Conversely, the soft, non-dense cross-linked structure in the Supersoft group was destroyed by the sponge, resulting in a rough surface. These results indicate that mechanical cleaning using a denture brush or a sponge should not be performed for soft relining materials with low Shore A hardness because it leads to surface roughness.

In the Soft group, Sa and Sz increased following immersion in Hypochlorite compared with Water. In the Supersoft group, Sa and Sz were also larger following immersion in Hypochlorite compared with Water. The surface roughness of Hypochlorite was considered to increase by the cross-linked structure of the silicone soft relining material owing to the oxidizing action of the denture cleanser. Peroxide-based neutral peroxide and alkaline peroxide denture cleansers have lower oxidizing properties than hypochlorite. The neutral peroxide and alkaline denture cleansers used in the current study contain peroxide, which has a bleaching effect. They also contain other acidic ingredients, such as citric acid, to nullify the effect [25]. This inhibition effect depends on the oxidizing properties of peroxide. These results indicate that neutral peroxide and alkaline denture cleansers have less influence on the surface properties of the silicone soft relining material than hypochlorite denture cleansers. The hypochlorite used had a pH of 12.5, whereas the alkaline hydrogen peroxide denture cleanser had a pH of 8.5 and neutral peroxide denture cleanser had a pH of 7.4. pH affects the ion content of the fluid; at pH < 7, the amount of hydrogen increases, whereas at pH > 7, the amount of hydroxide ions increases. A greater amount of hydroxide ions increases the denaturation properties of the fluid. Hence, alkaline or neutral peroxide denture cleansers with a pH close to 7 do not roughen the silicone soft relining material surface compared with hypochlorite denture cleanser with a high pH. Observations of the surface are considered to be consistent with the results of the measurements of surface roughness. The roughening of the specimens after the abrasion test could be observed with the naked eye and could be confirmed by obtaining scanning electron microscope image of low magnification (50 ×). However, in the immersion test, the difference in the surface quality of the specimens could not be confirmed by the naked eye; it could not be confirmed unless a scanning electron microscope image of high magnification (500 ×) was obtained. Observations showed that in the Soft and Supersoft groups, the surfaces were roughened after immersion in Hypochlorite. Similar results were also seen in the surface roughness measurements.
The surface roughness after cleaning is considered to be related with Shore A hardness. However, it cannot be concluded from the results of this study because only two types of silicone soft relining materials were used. This is because we chose the largest and smallest Shore A hardness because of time constraints. This is the limitation of the study.

It is recommended that silicone soft relining materials should only be cleaned by chemical cleaning to prevent the surface roughness caused by mechanical cleaning. However, fungi and bacteria attached to the denture are more effectively removed by a combination of chemical and mechanical cleaning. Therefore, both chemical and mechanical cleaning should be performed as long as the surface of the silicone soft relining material is not roughened. In the Soft group with high Shore A hardness, chemical cleaning with neutral peroxide denture cleanser or mechanical cleaning with sponge did not increase the roughness of the surface. The surface roughness of the silicone soft relining material remained the same after using a combination of chemical cleaning with a neutral peroxide denture cleanser and mechanical cleaning with a sponge as was after using mechanical cleaning alone (Suppl. data). Thus, the combination of chemical cleaning with a neutral peroxide denture cleanser and mechanical cleaning with a sponge is suitable for soft relining material with high Shore A hardness. In this study, in the group in which surface roughness increased after immersion in water and tap water, there is a possibility that adhesion of fungi increased after cleaning compared with before cleaning. However, adhesion of fungi was not observed in this study; hence, this cannot be concluded reliably.

5 Conclusions

In the abrasion test, cleaning with a sponge makes the surface of the silicone soft relining material less rough. In the immersion test, immersion in a neutral peroxide denture cleanser makes the surface of the silicone soft relining material less rough.

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Declaration of Competing Interest

There are no conflicts of interest to declare.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at
References
