An objective estimation of the removability of three home reliners

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The purpose of this study was to investigate methods for evaluating objectively the removability of three commercially available home reliners (Cushion Correct, Tafugurippu Pink A and Liodent Pink). After immersing each of the reliners in distilled water at 37°C for 24 h, we compared their removability using the peel test with a finger, which was evaluated based on a visual analogue scale and the percentage of the residual area. An experimental rake-up test was also undertaken to quantify removability, evaluated based on the total amount of work required to remove it. The Tafugurippu Pink A product was easier to remove with a finger than the other two home reliner products, and required the least total amount of work to be removed in the experimental rake-up test. Furthermore, the rake-up test performed could possibly be used for objective evaluation of the removability of home reliner.

**Keywords:** Home reliner, Experimental rake-up test, Peel test with finger, Shore E hardness, Type of failure

**INTRODUCTION**

Resorption of the alveolar ridge occurs in denture wearers over time1-4, so periodic visits to the dentist are needed to maintain a good fit between the denture base and the denture-bearing mucosa. However, a home reliner product, available in drugstores, can be used to temporarily improve the fit. A home reliner is a rubbery, cushioning substance that is applied to the intaglio surface of the denture to fill the gap between an ill-fitting denture and the denture-bearing mucosa. However, a home reliner product, available in drugstores, can be used to temporarily improve the fit. A home reliner is a rubbery, cushioning substance that is applied to the intaglio surface of the denture to fill the gap between an ill-fitting denture and the denture-bearing mucosa5. The home reliner has been shown to increase patient satisfaction with dentures and the efficiency of mastication6-9, but the device can change the occlusal relationship and exacerbate oral hygiene problems10-12. These issues are believed to arise when a home reliner is used to improve the fit of a denture base after use and the replacement home reliner is applied onto the remaining material13. Most patients need to manage the use of a home reliner by themselves, so it is important that these products are easy to remove from the denture base after use.

In its description of the peel test for a home reliner, the ISO-10873 standard14 recommends simply that the home reliner applied to an acrylic plate is removed using a finger or gauze, after which the plate should be checked visually for residual material. However, this method is a subjective evaluation only and is considered to be inadequate for assessing its removability. It is important to be able to evaluate the removability of home reliners objectively, in order to ensure their appropriate use. No other studies have attempted to evaluate the removability of home reliners in an objective manner. Bond strength testing for soft lining materials, including viscoelastic materials like the home reliner, includes the tensile, shear, and peel bond tests15-19. The home reliner is a material that tends to break when stretched and swells upon absorption of water, so it is difficult to use bond strength tests for soft lining materials when evaluating the removability of home reliners. For this reason, an experimental rake-up test using an experimental jig was performed to evaluate the removability of home reliners objectively.

This study compared the removability of three home reliner products using the peel test with a finger. Experimental rake-up test of home reliners applied to acrylic plates were also performed using an experimental jig to investigate methods for evaluating the removability of home reliners in an objective manner. The null hypothesis of this study was that there would be no significant differences among three home reliners with respect to the difficulty of removing the home reliner, the percentage of the residual area after the peel test with a finger, or in the total amount of work required for the rake-up test. We also performed tensile test and measured Shore E hardness to investigate the behavior of home reliners when peeled from a denture base.

**MATERIALS AND METHODS**

**Materials**

Table 1 shows the manufacturer and composition details for the three home reliners used in this study. Acrylic plates (80×50×5 mm; Delaglas AU-999, Asahi Kasei Technoplus, Tokyo, Japan) that conformed to ISO-7823-220 were used. Two types of acrylic plates were prepared: for one, the smooth surfaces of the plates were used as
Table 1 Home reliners tested

| Material        | Code | Manufacturer                        | Composition*                                      |
|-----------------|------|-------------------------------------|--------------------------------------------------|
| Cushion Correct | CC   | Shionogi, Osaka, Japan              | Polyvinyl acetate, Ethyl alcohol                  |
| Tafugurippu Pink A | TG | Kobayashi Pharmaceutical, Osaka, Japan | Polyvinyl acetate, Ethyl alcohol, Aminoalkylmethacrylate copolymer RS |
| Liodent Pink    | LD   | Lion, Tokyo, Japan                  | Polyvinyl acetate, Ethyl alcohol, White beeswax, Light calcium carbonate |

*Composition as given by manufacturers

received; for the other, the surfaces of the plates were roughened with SiC abrasive paper (#600). In all tests, the acrylic plates were used after being immersed in distilled water at 37°C for 24 h.

**Methods**

1. Peel test with finger
As shown in Fig. 1, three home reliner products (10×30×1 mm) were applied to the acrylic plates with a finger using polytetrafluoroethylene (PTFE) molds. Three home reliners each were applied on ten smooth plates (Smooth group) and on ten plates roughened with SiC abrasive paper (#600 group). After removal of the molds and immersion in distilled water at 37°C for 24 h, the plates were left for 15 min at room temperature and then used as the test specimens. A home reliner hardens when immersed in water for up to 24 h because the ethyl alcohol, added as a solvent, leaches out, and there is little change in viscoelasticity after this point13). In other words, the removability of a home reliner should be evaluated after the ethyl alcohol has leached out and the material is in a hardened state. For this reason, we immersed each home reliner in water for 24 h prior to testing. We recruited ten study participants (six men, four women, mean age 28.2 years) who had no problems with their fingers or vision. The subjects were instructed to remove the home reliner from the acrylic plate as best as they could using a finger. All participants performed one peel test in both groups. The experiment was conducted at a room temperature (23±2°C).

Difficulty of home reliner removal was evaluated using a 100 mm visual analogue scale (VAS), which is a subjective evaluation method. The participants made perpendicular lines indicating how difficult the home reliners were to remove on a 100 mm line, with the left edge (0 mm) indicating “easy to remove” and the right edge (100 mm) indicating “could not remove”. The distance from the left edge to the perpendicular line was measured to determine the difficulty of removal in a numerical fashion, and median values were calculated. High VAS scores for a home reliner indicated that it was difficult to remove, while low scores indicated that it was easy to remove. In addition, the percentage of the residual area of home reliner remaining on the acrylic plate was calculated using ImageJ processing software\(^ {21,22}\), and median values were calculated. The specimens were also inspected visually after the tests to categorize the type of failure as follows: “adhesive failure”, i.e., the failure surface was between the home reliner and the acrylic plate; “cohesive failure”, i.e., the failure surface was within the home reliner; and “mixed failure”, i.e., a mixture of adhesive and cohesive failure. The study was approved by the ethics committee at the Tokyo Medical and Dental University (approval number 1265).

2. Experimental rake-up test
Each home reliner (10×30×1 mm) was applied with a finger using a PTFE mold to an acrylic plate masked with PTFE tape to create a 10 mm jig insertion area (Fig. 2). After removing the molds, the plates were immersed in distilled water at 37°C for 24 h. The plates were then left at room temperature for 15 min, after which the masking tape was removed and they were used as the test specimens. Five specimens of each of the three home reliner products were made for the smooth group and for the #600 group.

An experimental jig manufactured from Acrylonitrile Butadiene Styrene (ABS) resin was attached to a rheometer (RHEOMETER CR-500DX, Sun Scientific, Tokyo, Japan) to allow the experimental rake-up test to be performed. Figure 3a shows the dimensions of the lateral side of the experimental jig and Fig. 3b shows those of the upper side. Figure 4 shows the positional relationship between the home reliner and the jig at the start of the test. The experimental rake-up test...
was performed at a speed of 40 mm per min for a distance of 20 mm. The experiment was conducted at a room temperature (23±2°C). The total amount of work was calculated, and the initial load increase rate was also calculated based on the initial stage of the linear coefficient of the load displacement curve. Figure 5 shows a diagram of the total amount of work and the initial load increase rate. In addition, the specimens were checked visually after the test and categorized as adhesive failure, cohesive failure, or mixed failure, as done for the peel test with finger.

3. Tensile test
Each home reliner (15×40×1 mm) was applied with a finger using a PTFE mold on an acrylic plate that had been fully masked with PTFE tape. After immersing the plates in distilled water at 37°C for 24 h and then leaving them at room temperature for 10 min, the molds were removed and the plates were left for another 5 min, after which the home reliners were removed from the masked acrylic plates; these were then used as the test specimens. Five test specimens were prepared for each of the three types of home reliner. Tensile tests were performed using a rheometer with a grip distance of 35 mm and a testing speed of 40 mm per min. The experiment was conducted at a room temperature (23±2°C). Mean values were calculated for the maximum load of each home reliner product.
4. Shore E hardness test
The home reliners (45 mm diameter, 1 mm thick) were applied with a finger using PTFE molds on acrylic plates. After removal of the molds and immersion in distilled water at 37°C for 24 h, the plates were left at room temperature for 15 min and then used as the test specimens. Five arbitrary points on each home reliner were measured using a durometer (ASKER Durometer Type E, Kobunshi Keiki, Kyoto, Japan) and mean values were calculated. The experiment was conducted at a room temperature (23±2°C).

5. Statistical analysis
VAS scores (in the peel test with finger), residual area percentage (in the peel test with finger) and initial load increase rate (in the experimental rake-up test) were compared among the three types of home reliners using the Kruskal-Wallis test combined with the Steel-Dwass test. Total amount of work required (in the experimental rake-up test), maximum load (in the tensile test) and Shore E hardness were compared among the three types of home reliners using one-way analysis of variance combined with Tukey’s HSD test. The initial load increase rate (in the experimental rake-up test) for the three types of home reliners was compared between the smooth and #600 groups using the Mann-Whitney U test. JMP® 12.0.1 software (SAS Institute, Cary, NC, USA) was used for the statistical analysis. The significance level was set at 0.05.

RESULTS
Figure 6 shows typical images of the specimens used in the peel test with finger before immersion (a, b), before the peel test (c, d), and after the peel test (e, f) for the smooth group and the #600 group. Before the peel test (c, d), the specimens had been immersed in water, so they were swollen and had shrunken surfaces compared with before immersion (a, b). Figure 6 (e, f) shows that TG peeled off well at the interface between the home reliner and the acrylic plate in both the smooth group and the #600 group, and that CC peeled off well only in the smooth group. In the other conditions, the home reliner remained on the acrylic plate. Table 2 shows how these results were categorized in terms of adhesive failure, cohesive failure, or mixed failure. Regardless of surface roughness, most TG specimens peeled off at the interface. In contrast, no LD specimens peeled off at the interface. Figure 7 shows a comparison of the VAS scores. VAS scores for TG in the smooth and #600 groups were significantly lower ($p<0.05$) than those for the other two products.

Figure 8 shows the residual area percentage of the home reliner on the acrylic plate after the peel test with finger. TG peeled off well at the interface with the acrylic plate, so its residual area was nearly 0% regardless of surface roughness. CC was nearly 0% in the smooth group, but was affected by the surface roughness in the #600 group, where the residual area was increased to
Fig. 7 Boxplots of VAS scores (median, minimum, maximum, and interquartile range) for removability using the peel test with finger in the smooth and #600 groups. The dots in the boxplots present statistical outliers in the tested group. Bracket with * indicates a significant difference between home reliners (p < 0.05, Steel Dwass test).

Table 2 Type of failure for peel test with finger

| Group | Material | Cohesive | Mixed | Adhesive |
|-------|----------|----------|-------|----------|
|       | CC       | 0        | 2     | 8        |
| Smooth | TG       | 0        | 0     | 10       |
|       | LD       | 7        | 3     | 0        |
| #600  | CC       | 10       | 0     | 0        |
|       | TG       | 1        | 0     | 9        |
|       | LD       | 10       | 0     | 0        |

Fig. 8 Boxplots of residual area percentage (median, minimum, maximum, and interquartile range) using the peel test with finger in the smooth and #600 groups. The dots in the boxplots present the statistical outliers in the tested group. Bracket with * indicates a significant difference between home reliners (p < 0.05, Steel Dwass test).

nearly 100%. Regardless of surface roughness, LD did not peel off at the interface, so its residual area was nearly 100%.

Figure 9 shows the test specimens from the smooth group and the #600 group used in the experimental rake-up test before immersion (a, b), before the rake-up test (c, d), and after the rake-up test (e, f). The colored areas indicated by the arrows in the images before immersion
Fig. 9  Typical images of the specimens for the smooth and #600 groups before immersion in water (a, b), and before (c, d) and after (e, f) the experimental rake-up test. Colored areas showing a two-headed arrow indicate the masking area.

Fig. 10  Load-displacement curves for the smooth and #600 groups in the experimental rake-up test.
(a, b) and before the experimental rake-up test (c, d) are where the acrylic plates were masked with PTFE tape for insertion of the jig. The tape was removed before the experimental rake-up test was performed. The images for the smooth group and the #600 group after the test (e, f) show that TG (Smooth) had good removability, similar to the peel test with finger, but in the other conditions, the samples that had been compressed remained on the acrylic plate. Figure 10 shows the load-displacement curves for the three types of home reliners in the smooth group and the #600 group in the experimental rake-up test. In the load-displacement curve for TG (Smooth; Fig. 10c), load reached a maximum of about 20 N at around 2–3 mm of displacement, after which the initial load decreased, as shown by the arrow. In the other load-displacement curves (Fig. 10a, b, d–f), the load increased gradually to a maximum of around 40–50 N, then gradually declined. These curves do not show the decrease in initial load, as was seen for TG (Smooth). Figure 11 shows the total amount of work required for the experimental rake-up test. In the smooth group, the total amount of work required for TG removal was significantly lower \((p<0.05)\) than that for removal of the other two products. However, no significant difference in the total amount of work was observed among three home reliners in the #600 group. Figure 12 shows a comparison of the initial load increase rates. TG had the highest values of the three home reliners in both the smooth group and the #600 group. No significant difference in the initial load increase rate was observed between the smooth group and the #600 group for any of the home reliners. Table 3 shows the type of failure occurring in the experimental rake-up test. Adhesive failure was only observed with TG (Smooth). All the others showed cohesive failure.

Figure 13 shows a comparison of the maximum loads for the three home reliners in the tensile test, for which TG had the highest values.

Figure 14 shows a comparison of the Shore E hardness of the three home reliners. TG displayed the highest value of the three samples.
DISCUSSION

The results of this study indicated that there were significant differences among the three home reliners with respect to the difficulty of removing them, the percentage of the residual area after the peel test with a finger, and the total amount of work required in the smooth group for the rake-up test, but not for the total amount of work required in the #600 group. Therefore, the null hypothesis was partially accepted.

The experiments could not be performed before the home reliners were immersed in water because home reliners have high viscosity and bad operability prior to immersion. Furthermore, home reliners are inserted into the oral cavity and absorb water when they are removed after clinical use. Therefore, the experiments were performed only after the home reliners were immersed in water.

In our preliminary experiment, home reliners (2 mm thick, twice as thick as the reliners used in this study; 37°C) left at room temperature returned to room temperature (23±2°C) within 15 min. Therefore, in this study, after the molds were removed and immersed in distilled water at 37°C for 24 h, the plates were left at room temperature for 15 min to return them to room temperature and then used as test specimens.

Furthermore, in our preliminary experiment, the mean arithmetic roughness (Ra) of the surface of the denture base resin when the ordinary polishing procedure was used with a polishing bar (Shofu big silicone point R2, Shofu, Kyoto, Japan) was estimated as 0.62±0.06 µm. That of the acrylic resin plate roughened with SiC abrasive paper (#600) was 0.53±0.06 µm. Therefore, the surface roughness of the roughened acrylic resin plate used in this study well reflected the surface roughness of the actual denture base.

In the peel test with finger, TG produced a largest number of adhesive failures and had the smallest residual area percentage, which likely accounts for why it had low VAS scores. Regardless of surface roughness, the VAS scores for TG were significantly lower than those for CC and LD, indicating that participants rated TG as having good removability with a finger.

For the experimental rake-up test, ABS resin was chosen to make an experimental jig because it could be formed easily and would not scratch the surface of the acrylic plates. The jig was set up to the rheometer to have line contact with the acrylic plates throughout the
stroke to reduce friction. When immersed in water for 24 h, home reliners swell because of water absorption, so it is impossible to measure their cross-sectional areas or calculate stress accurately. For this reason, the same amount of home reliner was applied to the plates before immersion, and the results were evaluated not by stress but by load, which did not seem to be problematic for comparing and ranking removal force.

In the experimental rake-up test, the load-displacement curve for TG (Smooth) shows a decrease in initial load, as indicated by the arrow in Fig. 10c. This decrease in initial load for TG (Smooth) is different from what was observed with the other materials. The fact that only TG (Smooth) produced adhesive failure and that all of the other samples produced cohesive failure suggests that this decrease in initial load was created by peeling off at the interface. In addition, the total amount of work required for TG removal was significantly lower than that for the other two products in the smooth group. These results indicate that the experimental rake-up test can be used for objective evaluation of the removability of a home reliner.

Home reliners are difficult to remove from the denture base because the polyvinyl acetate, which constitutes a major proportion of home reliners, and polymethylmethacrylate, which constitutes a major proportion of denture bases, have a high affinity for each other. Home reliners do not contain materials related to chemical adhesion, so the adhesion mechanism between home reliners and the denture base resin is considered to be mainly due to mechanical adhesion. More cohesive failures occurred in the #600 group than in the smooth group (Tables 2 and 3), which also implies that mechanical adhesion influenced the adhesion mechanism.

The differences in removability among the materials were speculated to be due to composition differences. Aminoalkylmethacrylate copolymer RS included in TG and white beeswax and light calcium carbonate included in LD were added to improve the ease of peeling the reliner off the denture, so the aminoalkylmethacrylate copolymer RS was considered to be important for peeling the TG off from the denture. In contrast, the white beeswax and light calcium carbonate included in LD were not effective in our study. In addition, the molecular weight was different among the three products used in this study, which were assumed to influence the removability of the home reliners. No other studies have attempted to evaluate the removability of reliners based on the added substances and the molecular weight. Thus, the added substances and the molecular weight, which influence the removability of home reliners, should be evaluated further.

In the initial stage of the experimental rake-up test, the home reliners were compressed by the head of the jig until they peeled off. The increase rate of the initial load reflects the compressive elastic modulus. The Shore E hardness of TG was higher than that of the other samples (Fig. 14). Shore E hardness is a hardness index used for soft materials, and a higher value indicates a stiffer material. Therefore, the initial load increase rate for TG was higher than that for the other samples (Fig. 12). Moreover, TG also had the highest maximum load in the tensile test, indicating that TG was the stiffest material and least likely to break. For a home reliner to peel off cleanly at the interface, it is important that cohesive failure does not occur before adhesive failure.

We believe that TG produced the most adhesive failure because it was the stiffest product and least likely to break. In bond tests for soft lining materials that are viscoelastic, such as the home reliner, stiffer materials undergo little deformation, causing a greater force to be transferred to the bond interface, thus producing adhesive failure. This is consistent with our findings.

The experimental rake-up test performed in this study may be able to evaluate the removability of stiff materials like TG (Smooth) in an objective manner. However, the test did not provide sufficient peeling for CC (Smooth) and TG (#600), as compared with peel test with finger showing Tables 2 and 3. This is probably because when peeling is performed with a finger, the action is done repeatedly, while peeling in the experimental rake-up test is only done with one stroke of the jig. In one-stroke jig movements involving soft materials, deformation occurs before the material can be peeled off at the interface, which makes it difficult for peeling force to be applied to the interface. In addition, the rake-up test was performed only at a speed of 40 mm per min. The moving speed of the jig influences the type of failure in the case of soft lining materials, because stress concentrates at a higher rate at the bond site. Therefore, it is necessary to evaluate the suitable moving speed of the jig. Further research will be necessary to explore more objective evaluation methods, such as investigating different jig hardness and shapes, varying the number of strokes, and changing the moving speed of the jig.

Within these limitation, the results of this study showed that not all home reliners examined were easy to peel off from the denture after use, and home reliners seemed to be even more difficult to remove from the rough surface of the denture base. Therefore, there is a risk that subsequent home reliners may be applied on top of the remaining materials. Home reliners should be used by denture wearers under the guidance of dentists for a short period. Evaluating the removability of home reliners is important because this evaluation could provide appropriate information to dentists and denture wearers.

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