

## Viscosity and adhesion strength of cream-type denture adhesives and mouth moisturizers

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We evaluated adhesion strength to acrylic resins under various experimental conditions and viscosity of 4 cream-type denture adhesives and 2 mouth moisturizers. The viscosity was determined by a sine-wave vibro viscometer. The adhesion strength tests were performed with 2 resin plates at a universal tester. In Method A, various constant thicknesses of material layer were tested and tensile strength was measured, while in Method B a constant load was applied before measurement. Five tests were carried out for each measurement. With Method A, adhesion strength increased exponentially as the layer got thin. Effect of the material thicknesses (contribution ratio  $\rho=79.0\%$ ) was much larger than that of material type ( $\rho=15.3\%$ ). Materials with higher viscosity had greater levels of adhesion strength in Method A, whereas those with the higher viscosity had lower levels of adhesion strength in Method B. Adhesion strength was significantly affected by the experimental condition prior to applying tension.

**Keywords:** Denture adhesive, Mouth moisturizer, Viscosity, Adhesion strength

### INTRODUCTION

Denture stabilizing materials<sup>1)</sup> available on the retail market are often used by denture wearers to improve ill-fitting dentures. Use of such materials is considered likely to increase among denture patients, as the number who need complete dentures is increasing. These materials can be divided into denture adhesives and home reliners<sup>2)</sup>, with denture adhesives available in cream, powder, and tape forms, and home reliners in cushion form. Denture adhesives provide a highly viscous layer between the denture intaglio surface and denture-bearing mucosa by absorbing saliva<sup>3)</sup>, resulting in increased stability and retention of ill-fitting dentures. Home reliners fill the gap between the denture intaglio surface of ill-fitting dentures and denture-bearing mucosa, resulting in fit enhancement.

In our previous study, we demonstrated that home reliners are not suitable for improvement of ill-fitting dentures because of low durability, *i.e.*, they showed dramatic changes in viscoelastic properties and had a considerably high percentage of water absorption over time<sup>4)</sup>. In addition, long-term use of those materials has been reported to cause bone loss of residual ridge because of tissue irritation, inequitable distribution of masticatory force on denture-bearing mucosa, and malocclusion by the hard materials<sup>5)</sup>.

The clinical efficacy of denture adhesives, such as masticatory performance, retention, and stability of dentures, has been reported in various studies<sup>6-11)</sup>, in which denture adhesives were found to improve retention and stability of both well- and ill-fitting dentures, though the efficacy was greater with ill-fitting dentures<sup>8)</sup>. These materials are also beneficial for denture patients in regard to comfort, reduction of tissue irritation, and psychological security<sup>12)</sup>. Additionally, it has been shown

that denture adhesives in cream form are a useful adjunct for denture prosthesis services during both the fabrication and post-insertion phases<sup>13)</sup>.

Cream-type denture adhesives are supplied in a tube as a low viscosity ointment and are mainly comprised of water-soluble polymers with high levels of stickiness, such as sodium carboxymethyl cellulose, methoxyethylene/maleic anhydride copolymer, polyethylene glycol and polyethylene oxide<sup>2,3)</sup>. Auxiliary components, such as peeling promotion agents, antiseptic, pH control chemicals, pigments, and flavor, are also contained in denture adhesives. Liquid paraffin and petrolatum provide a creamy condition as ointments, and are considered to function as peeling promotion agents, while pH control chemicals such as sodium dihydrogenphosphate control pH within a suitable range, and prevent deterioration and changes in the color of denture adhesives. Furthermore, propyl parahydroxybenzoate, no. 3 aluminium lake, and l-menthol are added as antiseptic, pigment, and flavor factors, respectively. Previous studies investigated the basic properties of cytotoxicity<sup>14-16)</sup> and microbial contamination<sup>17)</sup> of denture adhesives. On the other hand, the adhesion strength of denture adhesives is an important factor, as it directly influences retentive force between the denture and denture-bearing mucosa. In several previous studies, adhesion strength was evaluated based on the force necessary to separate the materials from glass or resin plates after application of a constant load<sup>16,18,19)</sup>, which has also been adopted as a method by specification 10873 in the International Organization for Standardization (ISO)<sup>20)</sup>. However, adhesion strength is also influenced by experimental conditions, including the thickness of material layer between the plates before tensile measurement. In order to evaluate adhesion strength in a more multilateral

manner, it is necessary to assess and compare the experimental conditions utilized.

In addition to denture adhesives, mouth moisturizers are also used to increase denture retention<sup>21)</sup> though their main purpose is to improve comfort in patients with xerostomia. Their materials consist of a wetting agent and base, along with several auxiliary components such as sweetening agents, binders, and native enzymes<sup>22)</sup>. They are mainly comprised of hydrogenated starch hydrolysate, polyglycerol methacrylate and hydroxyethylcellulose. Polyglyceryl methacrylate, sorbitol, and milk protein extract are included as wetting agents. Furthermore, antimicrobial host proteins such as lactoferrin, lysozyme, and lactoperoxidase are added to improve the symptoms of dry mouth of patients diagnosed with Sjogren's syndrome and those subjected to irradiation<sup>23)</sup>. Finally, xylitol and maltitol are used as sweetening agents, and aloe vera as a humectant and flavoring agent.

Evaluations of viscosity and adhesion strength of denture adhesives and mouth moisturizers are considered to be important, because these properties influence clinical efficacy, such as adaptation between the denture intaglio surface and denture-bearing mucosa, retention and stability of dentures, and durability. In the present

study, we evaluated the viscosity, adhesion strength to denture base acrylic resins, and the correlation between viscosity and adhesion strength of cream-type denture adhesives and mouth moisturizers. In addition, the experimental conditions used for examining adhesion strength before tensile measurement were also evaluated.

## MATERIALS AND METHODS

Four cream-type denture adhesives and 2 mouth moisturizers were tested. Each is shown in Table 1, together with the product code, manufacturer, and general composition.

### Viscosity

Viscosity ( $\eta$ ) of the test materials was determined using a sine-wave vibro viscometer (SV-100, A & D Co. Ltd., Tokyo, Japan) (Fig. 1). This instrument has 2 thin sensor plates driven with electromagnetic force at the same frequency by vibrating at constant sine-wave vibration in reverse phase, similar to a tuning fork. The electromagnetic drive controls the vibration of the sensor plates to keep them in constant amplitude. The driving electric current, which is an excitation force, is

Table 1 Cream-type denture adhesives and mouth moisturizers tested

Material	Code	Batch no.	Manufacturer	Composition*
Denture adhesive				
Correct Cream	CC	8G01	Shionogi & Co., Ltd., Osaka, Japan	Methoxyethylene/maleic anhydride copolymer, Petrolatum, Sodium carboxymethyl cellulose, Polyethylene glycol, Liquid paraffin, No.3 Aluminium lake
Liodent Cream	LC	61321	Lion Corporation, Tokyo, Japan	Sodium carboxymethyl cellulose, Polyethylene oxide, Paraben, Liquid paraffin, Sodium dihydrogenphosphate, l-Menthol
New Poligrip S	NP	H2908K	Earth Chemical Co., Ltd., Tokyo, Japan / GlaxoSmithKline K.K., Tokyo, Japan	Methoxyethylene/maleic anhydride copolymer, Petrolatum, Sodium carboxymethyl cellulose, Propyl parahydroxybenzoate, No.3 Aluminium lake
Tafugurippu Kurimu	TK	L8003	Kobayashi Pharmaceutical Co., Ltd., Osaka, Japan	Methoxyethylene/maleic anhydride copolymer, Petrolatum, Sodium carboxymethyl cellulose, Propyl parahydroxybenzoate, Liquid paraffin
Mouth moisturizer				
BioXtra Aqua Mouth Jell	BX	G2/1	Bio-x Healthcare, Gembloux, Belgium	Sorbitol, Milk protein extract, Lactoferrin, Polyglyceryl methacrylate, Aloe vera, Xylitol, Maltitol, Calcium lactate
Oral Balance	OB	61102	Laclede, Inc., Los Angeles, CA, U.S.A.	Hydrogenated starch hydrolysate, Polyglyceryl methacrylate, Xylitol, Hydroxyethylcellulose, D-glucose, Lysozyme, Aloe vera, Lactoperoxidase, Lactoferrin, Glucose oxidase, Potassium thiocyanate

\* Composition as given by manufacturers and Reference 2)

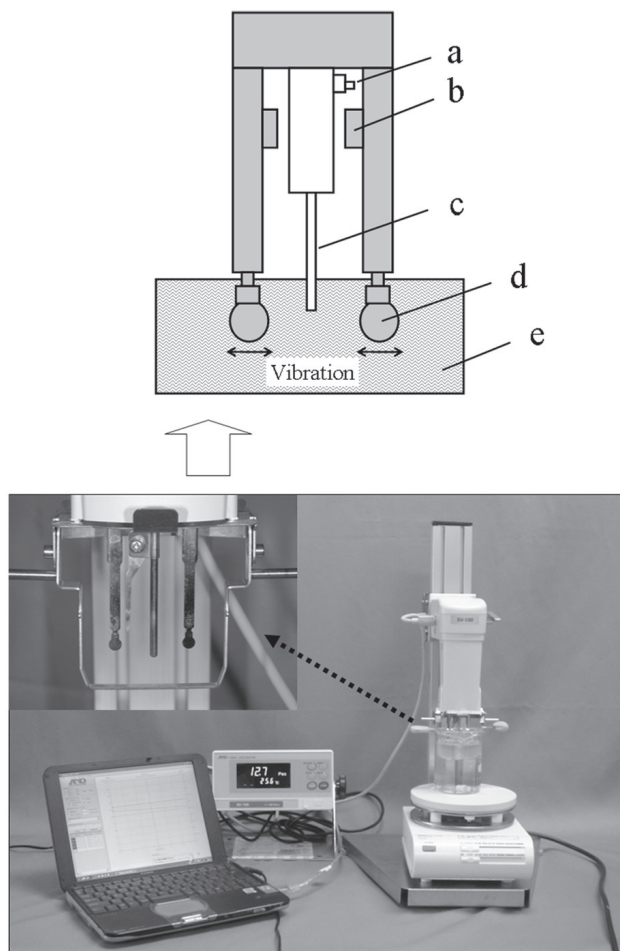


Fig. 1 Sine-wave vibro viscometer. (a): displacement sensor, (b): electromagnetic drive unit, (c): temperature sensor, (d): sensor plate, (e): sample.

detected as the magnitude of viscosity produced between the sensor plates and sample. A hot plate stirrer (SRS311HA, Advantec, Tokyo, Japan) was also used for temperature control. For each examination, 10 mL of test material was poured into the sample cup of the viscometer, then a series of tests was conducted from 20–50°C at a heating rate of 1°C/min. Five tests were carried out for each material.

#### Adhesion strength

The adhesion strength of the test materials placed between acrylic resin plates was determined using a compact table-top universal tester (EZ Test / CE, Shimadzu Corp., Kyoto, Japan) with 2 methods described below (Fig. 2). A pressure sensitive shaft with a circular base with a diameter of  $20.0 \pm 0.5$  mm made of heat-polymerized denture base acrylic resin (Acron, GC Corp., Tokyo, Japan) was fixed at the position of the load detector of the universal tester. A sample holder made of acrylic resin with an indentation sized  $22 \pm 1$  mm in diameter and a depth of  $0.5 \pm 0.1$  mm was fixed onto the

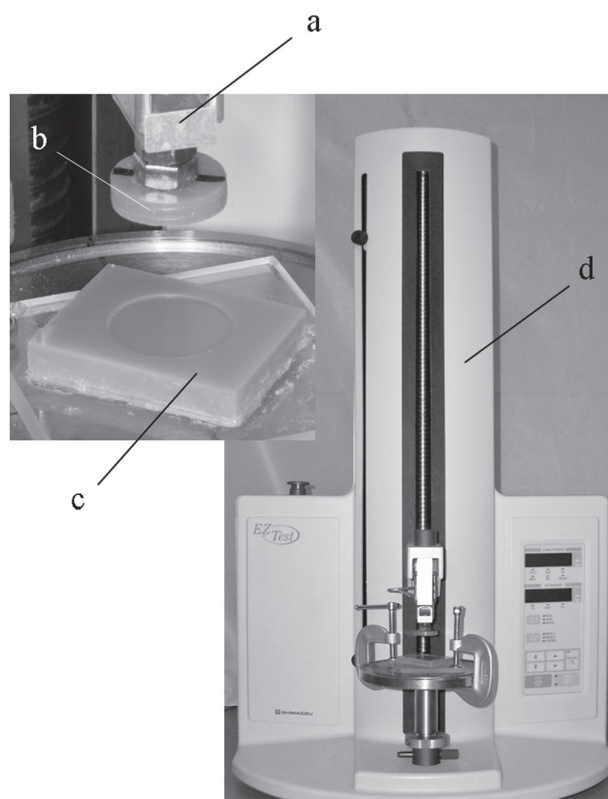


Fig. 2 Apparatus for measuring bond strength of denture adhesives. (a): load detector, (b): pressure sensitive shaft, (c): sample holder, (d): compact table-top universal tester.

sample stand of the tester. The shaft and sample holder of acrylic resin were abraded with 1,000-grit silicon-carbide paper. These comply with ISO specification 10873<sup>20)</sup>.

In Method A, we applied a constant gap prior to tensile measurement to produce a constant thickness of material layer. One mL of the test material was placed in the indentation of the holder and the surface of the material was flattened. Constant gaps of 0.10, 0.25, 0.50, 1.00, 1.50, and 2.00 mm between the shaft and sample holder were applied, with the position held for 30 s to reduce the influence of stress relaxation of the materials. Excess material that flowed out from the gap was trimmed by the plastic spatula before measurement. The shaft was then pulled in opposite direction at a cross-head speed of 5 mm/min.

In Method B, we applied a constant load prior to tensile measurement. Adhesion strength was determined according to ISO specification 10873 (2010)<sup>20)</sup>. One mL of the test material was placed in the indentation of the holder. A constant load up to  $9.8 \pm 0.2$  N was applied by the pressure sensitive shaft to the materials, with the position held for 30 s. The shaft was then pulled in the opposite direction at a cross-head speed of 5 mm/min.

For both methods, the maximum force detected

by the shaft was recorded and the force per unit area (adhesion area:  $10 \times 10 \times 3.14 = 314 \text{ mm}^2$ ) was calculated as adhesion strength. All experimental procedures were done at a room temperature of  $23 \pm 1^\circ\text{C}$ . Five tests were performed for each material and each experimental condition.

*Statistical analyses*

Comparisons of  $\eta$  values at  $23^\circ\text{C}$  and adhesion strength obtained with both methods were subjected to one-way analysis of variance (ANOVA) combined with a Student-Newman-Keuls test, with a 5% level of significance. Comparisons of the adhesion strength obtained with Method A were subjected to 2-way ANOVA, and the contribution ratios ( $\rho$ ) of type of material, thickness of material, and interaction for adhesion strength were also determined. Regression analyses were used to determine the correlation between  $\eta$  value and adhesion strength obtained with both methods. For all statistical analyses, we used SPSS Statistics 17.0.

RESULTS

Figure 3 shows influence of temperature on the viscosity ( $\eta$ ) value for the 6 tested materials. The  $\eta$  values for the

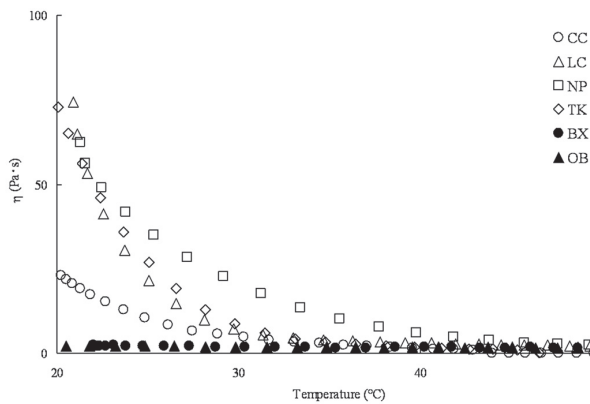


Fig. 3 Graphs showing viscosity ( $\eta$ ) versus temperature for 4 cream-type denture adhesives and 2 mouth moisturizers.

cream-type denture adhesives decreased exponentially with increases in temperature, whereas the mouth moisturizers exhibited nearly no changes in values with temperature changes. All of the denture adhesives demonstrated higher  $\eta$  values (CC:  $15.1 \pm 1.3 \text{ Pa}\cdot\text{s}$ ; LC:  $42.7 \pm 4.2 \text{ Pa}\cdot\text{s}$ ; NP:  $44.5 \pm 4.3 \text{ Pa}\cdot\text{s}$ ; TK:  $43.8 \pm 4.5 \text{ Pa}\cdot\text{s}$ ) than the mouth moisturizers (BX:  $2.3 \pm 0.5 \text{ Pa}\cdot\text{s}$ ; OB:  $2.2 \pm 0.6 \text{ Pa}\cdot\text{s}$ ) ( $p < 0.05$ ), with the value for CC lowest among the denture adhesives at  $23^\circ\text{C}$ . No significant differences were found for the  $\eta$  value among the denture adhesives NP, TK, and LC.

Figure 4 shows adhesion strength, which was obtained with application of a constant thickness of the material layer before tensile measurement (Method A) for each of the 6 materials. The influence of the thickness of the material layer between the acrylic resin plates on adhesion strength was evaluated. All of the materials showed adhesion strength that increased exponentially as the thickness of the material layer between the

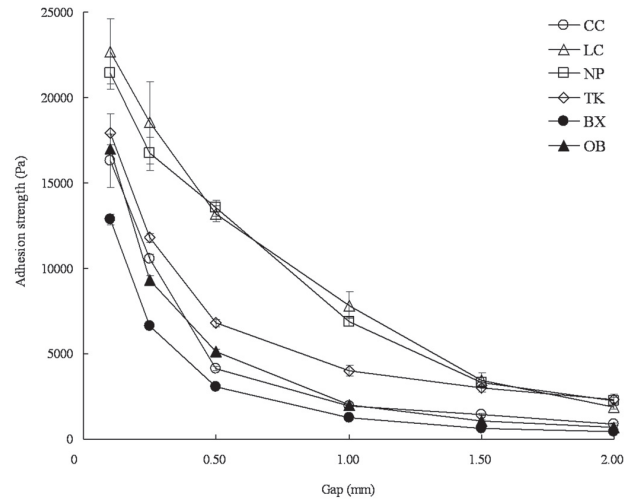


Fig. 4 Influence of thickness of material layer on adhesion strength of 4 cream-type denture adhesives and 2 mouth moisturizers. Adhesion strength was obtained by using a constant material thickness prior to tensile measurement (Method A).

Table 2 Two-way ANOVA for the adhesion strength by Method A of 4 cream-type denture adhesives and 2 mouth moisturizers

Source	df	Sum of Squares	Mean Square	F	Significance of F	Contribution Ratio $\rho$ (%)
Material Type	5	$1.230 \times 10^9$	$2.460 \times 10^8$	517.008	0.000	15.3
Material Thickness	5	$6.356 \times 10^9$	$1.271 \times 10^9$	2670.970	0.000	79.0
Material Type $\times$ Material Thickness	25	$3.882 \times 10^8$	$1.553 \times 10^7$	32.626	0.000	4.7
Error	144	$6.853 \times 10^7$	475902.851			1.0
Corrected Total	179	$8.043 \times 10^9$				

acrylic resin plates became thinner and the differences among the materials were large as the thickness decreased. Furthermore, the adhesion strength of the denture adhesives, especially LC and NP, tended to be higher than that of the mouth moisturizers with

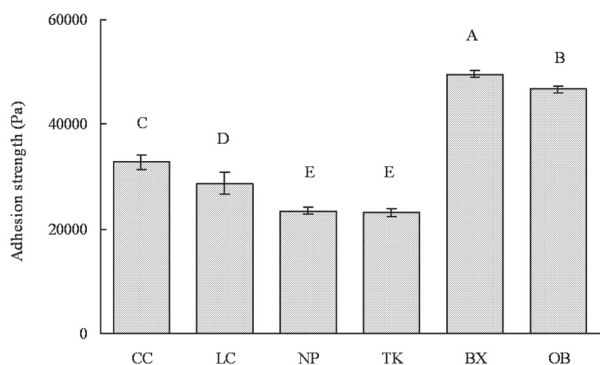


Fig. 5 Adhesion strength with a constant load applied prior to tensile measurement (Method B) for 4 cream-type denture adhesives and 2 mouth moisturizers. Identical letters indicate no significant difference.

all of the tested thicknesses, while BX exhibited the lowest adhesion strength among the materials tested at all thicknesses. Our 2-way ANOVA results indicated significant differences among the materials ( $p < 0.0005$ ) and significant effects by material thickness ( $p < 0.0005$ ) for adhesive strength determined with Method A (Table 2). However, a wide range of contribution ratios ( $\rho$ ) was found between the material thickness and material type factors, with adhesive strength more influenced by material thickness ( $\rho = 79.0\%$ ) than type of material ( $\rho = 15.3\%$ ). Although there was a significant interaction between the materials and material thickness ( $p < 0.0005$ ;  $\rho = 4.7\%$ ), the effect was not large.

Adhesion strength values obtained by applying a constant load prior to tensile measurements (Method B) are shown in Fig. 5. The adhesion strength of both mouth moisturizers (BX and OB) was significantly higher than that of the 4 denture adhesives ( $p < 0.05$ ), while CC had the highest adhesion strength among the denture adhesives with this method.

Cohesive failure was observed at all tests in both methods.

Regression analyses of plots of adhesion strength obtained with Method A and B against the  $\eta$  values of the

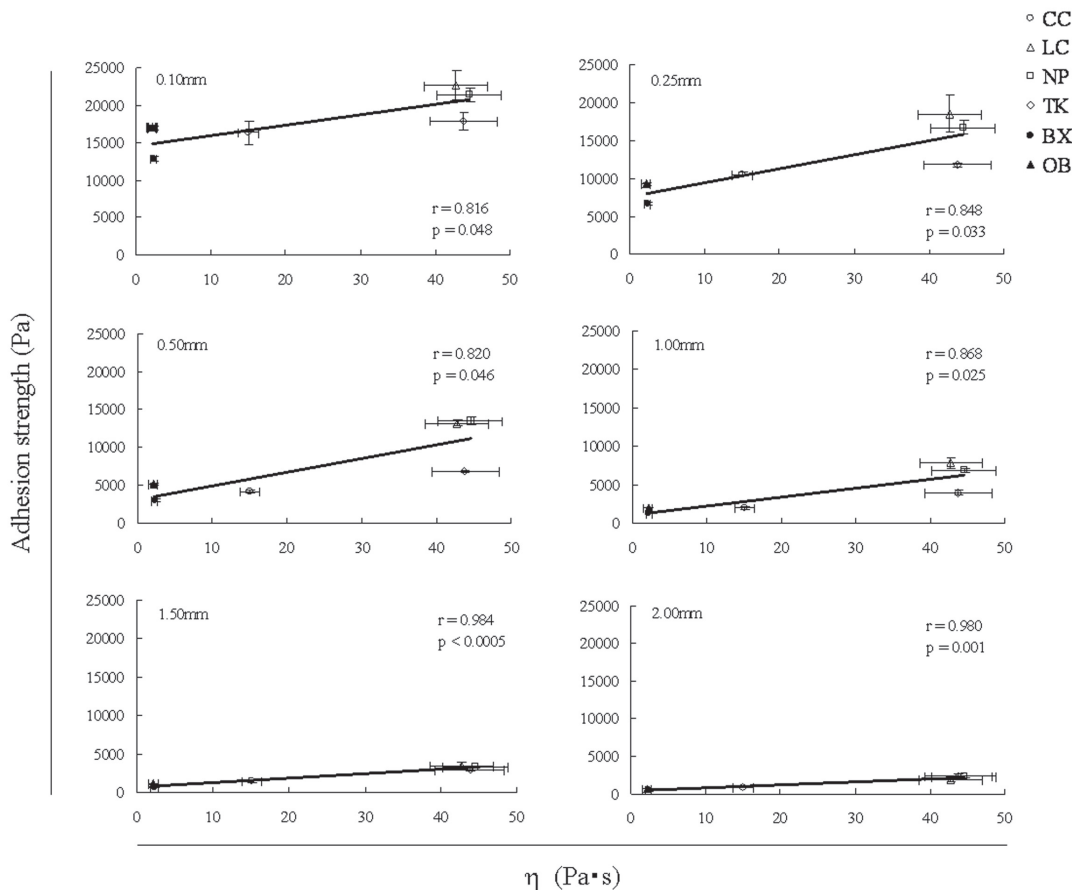


Fig. 6 Correlation between viscosity ( $\eta$ ) values and adhesion strength obtained with Method A at the tested material thickness for 4 cream-type denture adhesives and 2 mouth moisturizers.

6 materials are presented in Figs. 6 and 7, respectively. With Method A, adhesion strength was analyzed with different material thicknesses, and a positive linear correlation was found between adhesion strength

with Method A and the  $\eta$  value (Fig. 6). On the other hand, a negative linear correlation was found between adhesion strength obtained with Method B and the  $\eta$  value (Fig. 7). Figure 8 demonstrates the relationship between adhesion strength obtained by the 2 methods and inconsistency found between them.

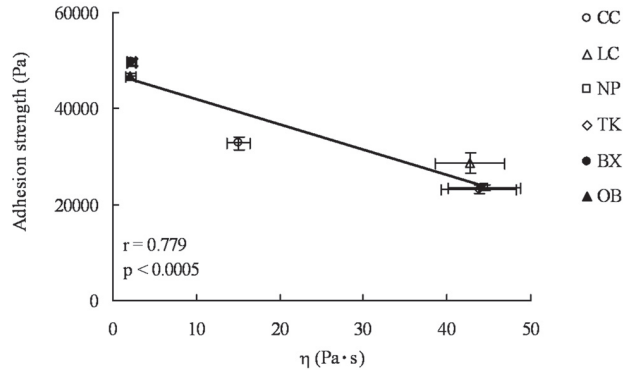


Fig. 7 Correlation between viscosity ( $\eta$ ) values and adhesion strength obtained with Method B for 4 cream-type denture adhesives and 2 mouth moisturizers.

### DISCUSSION

The present findings demonstrate that materials with higher viscosity have higher adhesion strength when applied at a constant thickness of each material, which is produced by application of a constant gap between experimental plates, prior to tensile measurement. On the other hand, the adhesion strength value obtained with application of a constant thickness of material layer was not consistent with that obtained with a constant load.

We found large differences in the relationships between temperature and viscosity among the tested materials. The viscosity of the cream-type denture adhesives, especially LC, TK, and NP, was sensitive to changes in temperature, with 82% to 93% decreases

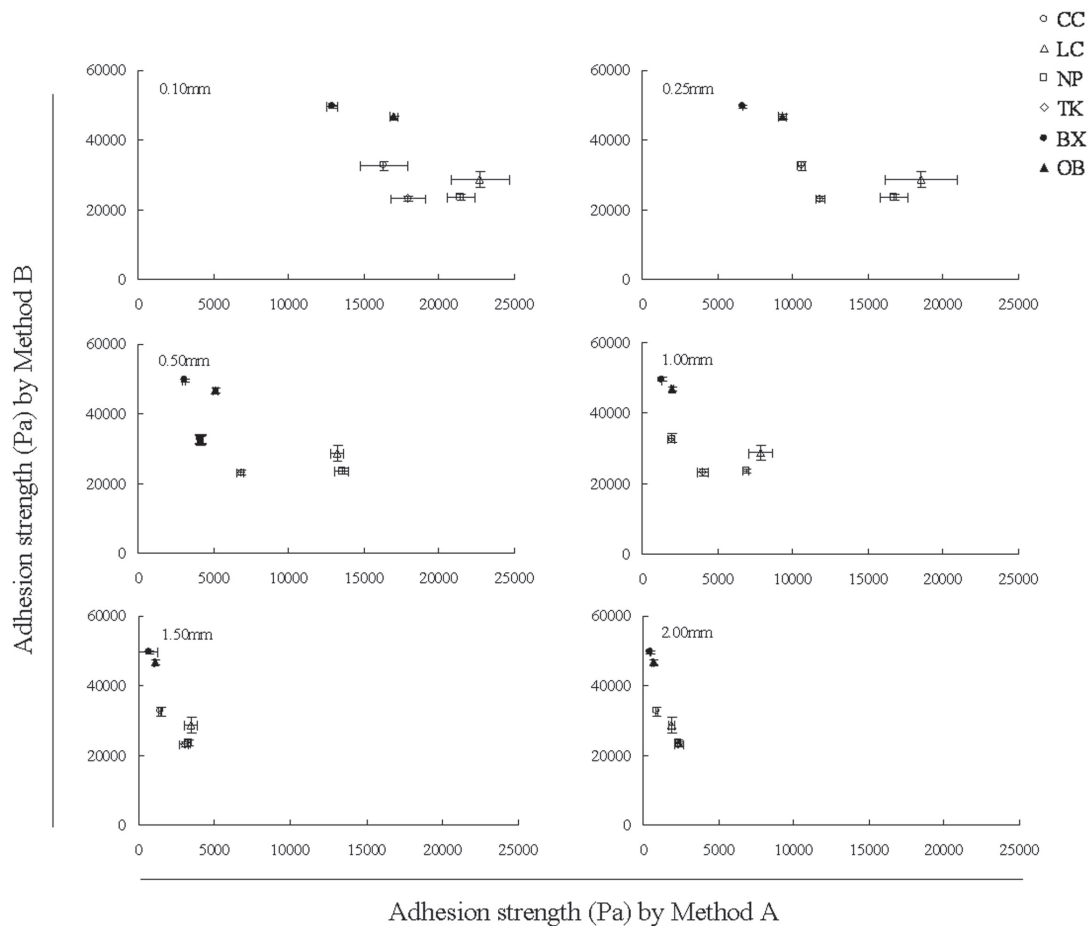


Fig. 8 Relationship between adhesion strength obtained with Method A and that with Method B for 4 cream-type denture adhesives and 2 mouth moisturizers.

noted from 23°C to 37°C. In contrast, the viscosity of the mouth moisturizers was not influenced by temperature. Large differences in viscosity values were also found among the materials and we noted 3 statistically significant groupings in regard to the viscosity of the materials tested at 23°C (NP,TK,LC>CC>BX,OB). That of the denture adhesives NP, TK, and LC was approximately 43 Pa·s. Although CC was also classified as a denture adhesive, its viscosity (approximately 15 Pa·s) was much lower than that of the other 3. As a result, CC is easy to spread onto the denture intaglio surface and denture-bearing mucosa as compared to the other adhesives. On the other hand, this material has a higher possibility of flowing out from the denture shortly after application due to its lower viscosity, which would cause a reduction in the adhesive effect, and lead to decreases in stability and retention of the denture. It has been reported that the clinical efficacy of OB did not last more than 1–2 h, while that of BX was greater than 2 h in some patients<sup>22</sup>. In addition, the durability of the adhesion strength of the tested mouth moisturizers will also be much lower as compared to the denture adhesives for the same reason. However, the mouth moisturizers would also spread equitably onto the intaglio surface of dentures and would not lead to the malocclusion though the interval of application is shorter than that of the cream-type denture adhesives. The washability is also better than that of denture adhesives. The mouth moisturizers will be useful to the denture patients especially with xerostomia.

The large differences in viscosity, which influences adhesion strength, seen among the cream-type denture adhesives could be attributed to their composition and structure. The viscosity of the main components such as sodium carboxymethyl cellulose, methoxyethylene/maleic anhydride copolymer, polyethylene oxide, and polyethylene glycol, which are water-soluble polymers<sup>2,3</sup> would influence the physical properties such as viscosity of the denture adhesives. The water-soluble polymers exist in the ointments such as liquid paraffin and petrolatum. The larger amount of the water-soluble polymers produces the materials with higher levels of viscosity. Furthermore, the higher average molecular weight and larger particle size of these polymers leads to higher viscosity. The larger content of the liquid paraffin (ointment) produces the lower viscosity of the denture adhesives. CC would contain larger percentage of the liquid paraffin than LC and TK, resulting in the lower viscosity. Furthermore, molecular weight and particle size of the sodium carboxymethyl cellulose<sup>24</sup> and methoxyethylene/maleic anhydride copolymer in CC may be lower than those of LC, NP, and TK. Temperature dependence in viscosity of TK, NP and CC would be ascribed to petrolatum because this component is more affected by change of temperature.

In the case of mouth moisturizers, difference between viscosity values of BX and OB was not found though the molecular weight of main ingredients such as polyglyceryl methacrylate, hydrogenated starch hydrolysate and hydroxyethylcellulose<sup>24</sup> included in

the materials may affect the physical properties. This is probably due to the large percentage of liquid components in these materials.

As noted above, the relationship among composition, viscosity, and adhesion strength is considered to be complex. Further study of the influence of composition on these properties is necessary to develop ideal denture adhesives and mouth moisturizers.

Denture retention is considered to be affected by many factors, including size, wettability, fit to denture-bearing mucosa, and quantity and viscosity of saliva. A previous study of the physical factors of saliva that affect denture retention used 2 parallel plates and demonstrated that viscosity of tested liquid plays an important role, with higher viscosity related to greater retentive force<sup>25</sup>. That study also found that the surface tension of the liquid and roughness of the denture base acrylic resin may not have a significant influence<sup>25</sup>. Thus the adhesion strength to denture base acrylic resins of the denture adhesives and mouth moisturizers would be also expected to be greatly influenced by the viscosity when these materials are applied instead of saliva. In the present study, one of the main focuses is to determine the influence of test methods on the adhesion strength. Therefore, this study evaluated the relationship between the viscosity and adhesion strength but not the only comparison among the viscosity of the materials. We used 2 parallel plates to investigate the retentive force of cream-type denture adhesives and mouth moisturizers with various viscosity levels and 2 experimental methods. The results obtained with a constant thickness of material layer before tensile measurement (Method A) are consistent with the above previous study. Materials with higher viscosity values tended to have higher adhesion strength to acrylic resin, as shown by regression analysis. Among the materials tested, the denture adhesives LC and NP exhibited the highest adhesion strength, while the mouth moisturizer BX the lowest. For example, LC and NP showed approximately 1.7-fold greater adhesion strength than BX at a material thickness of 0.1 mm. Thus, greater force was necessary to separate the materials with higher viscosity values from the plates when the thickness of material layer was constant. Scant information is available on the influence of thickness of denture adhesives and mouth moisturizers on retentive force. Thus, the influence of thickness of the tested material that was represented by the gap between the shaft and sample holder of the apparatus was also evaluated. It has been reported that relining of a denture is necessary when the gap between the denture intaglio surface and denture-bearing mucosa is more than 130  $\mu\text{m}$  (0.13 mm) in clinical situations<sup>26</sup>. Furthermore, the gap would amount to more than 1 or 2 mm when the teeth are extracted. Therefore, the material thickness from 0.10 to 2.00 mm was tested in the present study. We found that adhesion strength increased exponentially as the thickness of material layer decreased and that the effect of material thickness was much larger than that of type of material, as indicated by the contribution ratios obtained with ANOVA.

In previous studies, the adhesion strength of the denture adhesives was evaluated by examining the tensile strength of materials placed between acrylic resin plates with constant load applied before tension<sup>16,18,19,27,28</sup>, and the ISO specification for denture adhesives has adopted this experimental method<sup>20</sup>. In the present study, we compared this test method (Method B) with Method A. With Method B, materials with lower viscosity tended to have higher adhesion strength values, as shown by regression analyses comparing viscosity values and adhesion strength. The mouth moisturizers BX and OB showed the highest levels of adhesion strength, while the denture adhesives NP and TK had the lowest. Furthermore, BX and OB showed approximately 2-fold greater adhesion strength than NP and TK. Application of materials with lower viscosity resulted in less distance between the 2 plates, because a constant load of  $9.8 \pm 0.2$  N was applied to each sample before tension, thus higher adhesion strength was found. The results obtained by applying a constant load before tensile measurement (Method B) were not consistent with those obtained with a constant thickness of material layer (Method A). The order of the tested materials in regard to adhesion strength obtained by these 2 methods was reversed.

In the ISO specification 10873, a load of 9.8 N, *i.e.*, stress of 31.2 kPa, is applied before tension. It has been reported that the stress to the denture-bearing mucosa under complete dentures when crushing food ranged between approximately 13 and 589 kPa<sup>29</sup>. Although the stress of 31.2 kPa lies within this range, higher load would be desirable for more clinical evaluation in ISO specification, and further examination will be necessary.

Our results obtained by Method A demonstrated that patients should not apply a large quantity of denture adhesive, as only the minimum amount necessary to produce a thin layer between the denture intaglio surface and denture-bearing mucosa is needed, as that will lead to greater denture retention and stability. In addition, it is also necessary for patients to bite the denture sufficiently to spread the materials thinly on the denture intaglio surface. Generally, patients tend to use larger amounts of denture adhesives than necessary, resulting in a thicker lining layer, leading to less stability and retention. The minimum amount should be applied from the standpoint of washability and cytotoxicity, also, because the materials are difficult to remove from the denture-bearing mucosa and may contribute to mucosal inflammation after usage of large amount and for a long period of time<sup>30</sup>. When the degree of ill-fitting of the denture is larger, the effect of the denture adhesives on retention of the denture is low. The relining procedure or remaking of the denture should be conducted in this situation. The findings of the present study should be helpful when giving instructions to patients for effective use of denture adhesives.

We evaluated adhesion strength to denture base acrylic resins by various cream-type denture adhesives and mouth moisturizers using a simple jig that consisted of acrylic resin plates. However, there are many factors

that influence adhesion strength, such as the shape of the residual ridge, denture-bearing mucosa, condition of saliva, and temperature. A higher residual ridge and larger saliva flow would lead to higher retention and stability of dentures. Although the measurement at 37°C is more desirable clinically, the adhesion strength tests have been conducted at a room temperature of  $23 \pm 1$ °C in the present study according to some previous studies<sup>16,19</sup> due to the structure of universal tester. The measurement of the denture adhesives at 37°C would lead to lower adhesion strength in Method A and higher adhesion strength in Method B than that at 23°C, respectively, because the viscosity of the materials decreases with increases in temperature. In the case of the mouth moisturizers, the adhesion strength would not change because the viscosity of these materials exhibits no temperature-dependent properties. Thus the difference in adhesion strength between the denture adhesives and mouth moisturizers will be smaller when measured at 37°C. However, the main purpose of the present study is to evaluate the experimental conditions of the adhesion strength before tensile measurement, but not the actual values. Thus, this experimental condition is considered to lead to attainment of the purpose.

Adhesion strength in the present study was evaluated using 2 different methods; application of a constant thickness of material layer and application of a constant load prior to tensile measurements. When patients use denture adhesives correctly and the materials are applied thinly on the denture intaglio surface, as stated above, a constant material thickness method is more suitable for clinical evaluation of adhesion strength as compared with a constant load method. Nevertheless, further research into the effects of denture adhesives and mouth moisturizers on stability and retention of dentures in patients is necessary in order to determine a method suitable for clinical evaluations.

## CONCLUSION

Within the limitations of this study, we made the following conclusions.

1. The viscosity of cream-type denture adhesives decreased exponentially with increases in temperature, whereas that of the mouth moisturizers showed no temperature dependence. All of the tested denture adhesives had higher viscosity values than the mouth moisturizers.
2. With a constant thickness of material layer before tensile measurement (Method A), materials with higher viscosity values tended to have higher adhesion strength to acrylic resin.
3. Adhesion strength values increased exponentially as the thickness of material layer decrease.
4. The material thickness (contribution ratio  $\rho=79.0\%$ ) had a greater influence on adhesion strength than type of material ( $\rho=15.3\%$ ).
5. With a constant load applied before tensile measurement (Method B), materials with lower viscosity values tended to have higher adhesion



strength to acrylic resin.

6. The method that used a constant material thickness and the method that used application of a constant load differed significantly in regard to the results obtained for adhesion strength.

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