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ORIGINAL ARTICLE

The adhesive strength and initial viscosity of denture adhesives

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Abstract

Objective. To examine the initial viscosity and adhesive strength of modern denture adhesives *in vitro*. ***Materials and methods.*** Three cream-type denture adhesives (Poligrip S, Corect Cream, Liodent Cream; PGS, CRC, LDC) and three powder-type denture adhesives (Poligrip Powder, New Faston, Zanfton; PGP, FSN, ZFN) were used in this study. The initial viscosity was measured using a controlled-stress rheometer. The adhesive strength was measured according to ISO-10873 recommended procedures. All data were analyzed independently by one-way analysis of variance combined with a Student-Newman-Keuls multiple comparison test at a 5% level of significance. ***Results.*** The initial viscosity of all the cream-type denture adhesives was lower than the powder-type adhesives. Before immersion in water, all the powder-type adhesives exhibited higher adhesive strength than the cream-type adhesives. However, the adhesive strength of cream-type denture adhesives increased significantly and exceeded the powder-type denture adhesives after immersion in water. For powder-type adhesives, the adhesive strength significantly decreased after immersion in water for 60 min, while the adhesive strength of the cream-type adhesives significantly decreased after immersion in water for 180 min. ***Conclusion.*** Cream-type denture adhesives have lower initial viscosity and higher adhesive strength than powder type adhesives, which may offer better manipulation properties and greater efficacy during application.

Key Words: *denture adhesive, viscosity, adhesive strength*

Introduction

The number of complete denture wearers will rise with future increases in the elderly population. Denture adhesives, also referred to as adherents or fixatives, are materials used to bond and retain dentures in their designated suitable denture-bearing areas [1]. They play an important role in denture aftercare. Various studies have indicated that use of adhesives significantly decreases lateral and vertical movement of dentures during various activities, improves the incisal bite force [1–7], improves taste discrimination and taste perception [8], reduces the amount of food accumulating under the denture, increases chewing comfort [6,7], improves articulation [9] and increases confidence during social activities and chewing [10]. In addition, they are particularly useful for patients with special needs, such as poor neuromuscular control or xerostomia, as they can alleviate the patients' symptoms [11,12] and may also act as a cushion for denture-bearing mucosa that may be thinned by age or susceptible to irritation from lack of lubrication due to poor quality or quantity of saliva. It is clear that denture adhesives make life easier for denture wearers and act as an effective adjunct to denture treatment and denture aftercare [13]. Dental professionals have been slow to accept denture adhesives as a means to enhance denture retention, stability and function [14].

The use of denture adhesives continued to spread. Shay [15] reported that 15% of US denture wearers used adhesives in the 1980s, while Wilson et al. [16] reported in 1990 that 30% of denture wearers used or had used denture adhesives. Industry estimates of

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market size vary from 15–33% of denture wearers using denture adhesives on a regular basis [15]. Along with the aging of the world population and the increase in edentulous individuals, the total consumption of denture adhesives is increasing. However, dental professionals have focused little attention on these materials.

Denture adhesives contain active ingredients (water-soluble polymers) and non-active ingredients (base material). The active ingredients mainly responsible for the adhesive properties include karaya gum, tragacanth, acacia, pectin, gelatin, methyl cellulose, hydroxymethyl cellulose, sodium carboxymethyl cellulose and the synthetic polymers (polyethylene oxide, acrylamides, acetic polyvinyl) [10,11,17]. The non-active ingredients, such as petrolatum, mineral oil and polyethylene oxide, act as binding materials to facilitate placement [13,18,19]. The composition of denture adhesives has been changed over the years in order to improve the efficacy of the products. Pre-1960, the active ingredients were gum-based materials such as karaya gum. In the 1970s the effectiveness of denture adhesives was improved by adding calcium salts to the blend and in the 1980s improvement came from adding zinc to the previous formulations [11]. Carboxymethylcellulose (CMC) and polyvinylether methyl cellulose (PVM-MA) are often incorporated in some of today's adhesives [14].

Modern denture adhesives are available in different forms such as creams, strips, powders and cushions to fulfill a range of consumer preferences [10,11]. The properties of a denture adhesive vary according to its composition. Many different types of adhesives are currently available, so quantitative and *in vivo* assessments are needed to assist in selecting a suitable adhesive. Although several studies have investigated the clinical efficacy of denture adhesives, few studies have examined the initial viscosity and adhesive strength of denture adhesives *in vitro* [16]. Adhesive strength and viscosity are the most important properties of denture adhesives, as they govern the duration of effectiveness and the ease of manipulation. Information about these characteristics is important for clinical users of these materials.

The purpose of this study was to examine the initial viscosity and adhesive strength of modern denture adhesives *in vitro*. Our null hypothesis was that the adhesive strength of cream-type denture adhesives is maintained for longer than powder-type denture adhesives.

Materials and methods

Sample preparation

Three cream-type denture adhesives (Poligrip S, Corect Cream, Liodent Cream; PGS, CRC, LDC) and three powder-type denture adhesives (Poligrip Powder, New Faston, Zanfton; PGP, FSN, ZFN) were used in this study. Detailed information about the components of these materials is shown in Table I. Powder-type denture adhesive samples were prepared by mixing powder with distilled water in the ratio of 1:4.

Initial viscosity measurement

The initial viscosity of the materials was measured using a controlled-stress rheometer (CarriMed CSL500, TA Instruments Ltd, New Castle, DE) in dynamic mode with a cone-and-plate configuration in consultation with a former study (Figure 1) [20,21]. The instrument was used in a constant strain mode with an angular velocity of 10 rad/s at 37°C. Five separate specimens were measured for each material.

Adhesive strength measurement

The adhesive strength was measured according to ISO-10873 recommended procedures [22]. The hole of the sample holder was filled with denture adhesive and the surface was flattened. The sample holder was then immersed in water at 37°C for 0, 1, 10, 30, 60, 180 or 360 min, removed and shaken once

Table I. Commercial denture adhesives tested.

Code	Materials	Manufacturer	Components	Type
PGS	Poligrip S	Glaxo Smith Kline K.K., Tokyo, Japan	PVM-MA, CMC sodium propyl parahydroxy-benzoate	Cream type
CRC	Corect Cream	Shionogi & Co., Ltd., Osaka, Japan	PVM-MA, CMC sodium, polyethylene glycol	
LDC	Liodent Cream	Lion Co., Tokyo, Japan	CMC sodium, polyoxyethylene oxide, liquid paraffin, sodium dihydrogenphosphate	
PGP	Poligrip Powder	Glaxo Smith Kline K.K., Tokyo, Japan	CMC sodium, PVM-MA	Powder type
FSN	New Faston	Lion Co., Tokyo, Japan	Karaya gum powder	
ZFN	Zanfton	Showa Yakuhin Kako Co., Ltd., Tokyo, Japan	Sodium polyacrylate	

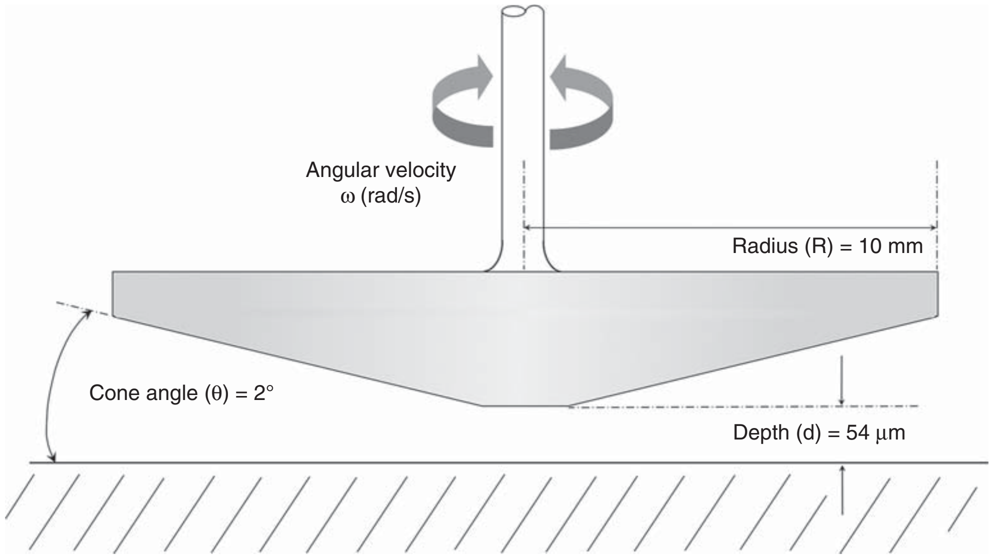

Figure 1. Block diagram of viscosity test jig [20,21].

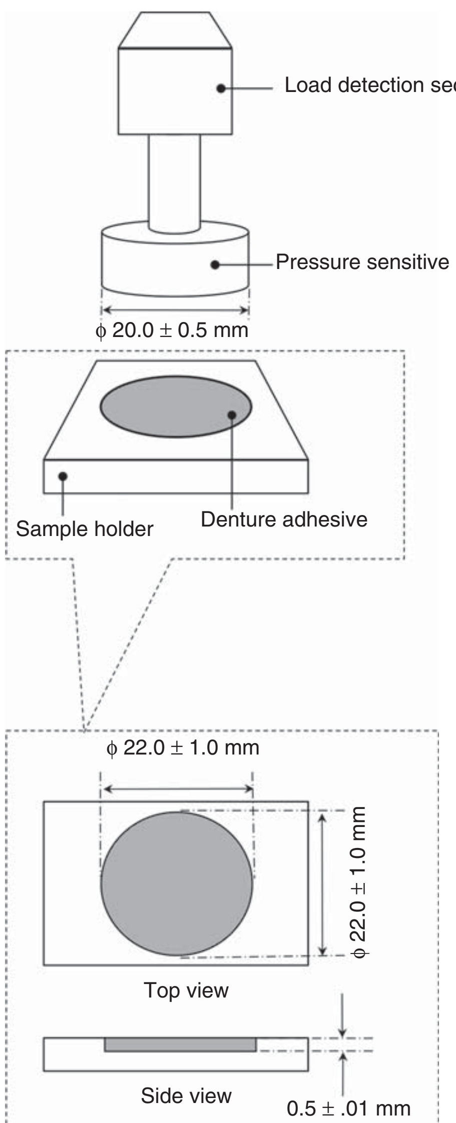

Figure 2. Block diagram of sample holder for adhesive strength test [20,21].

to remove water from the sample surface (Figure 2). The sample holder was then fixed on the sample stand [20,21] and a load of 9.8 ± 0.2 N was applied to the sample using a constant load compression testing machine (A-001, Japan Mecc Co. Ltd, Tokyo, Japan) at a pressurizing velocity of 5 mm/min using a 20 ± 0.5 mm pressure sensitive knob and maintained for 30 s. The sample was then pulled in the reverse direction with tensile velocity using a materials testing machine (Model 5565, Instron Co., Canton, MA) at a crosshead speed of 5 mm/min. Five separate specimens were measured for each material. The maximum force on the pressure sensitive knob was measured at that time and the force per unit area was set as the adhesive strength. The sample holder and pressure sensitive knob were prepared using denture base acrylic resin (Acron, Lot No. Powder-030471, Liquid-0112203; P/L:10/4.3 g; GC Corp., Tokyo, Japan) and were polymerized according to the manufacturer's instructions. The surfaces were abraded with 400 grit waterproof abrasive papers, rinsed with tap water for 15 s and allowed to air dry for at least 5 min.

Statistical analysis

All the data were analyzed independently by one-way and two-way analysis of variance (ANOVA) combined with a Student-Newman-Keuls (SNK) multiple comparison test at a 5% level of significance. All analyses were computed with IBM SPSS Statistics for Windows (IBM SPSS Statistics 22, IBM Japan Corp., Tokyo, Japan).

Results

Figure 3 shows the initial viscosity of the materials tested. Significant differences were found between the

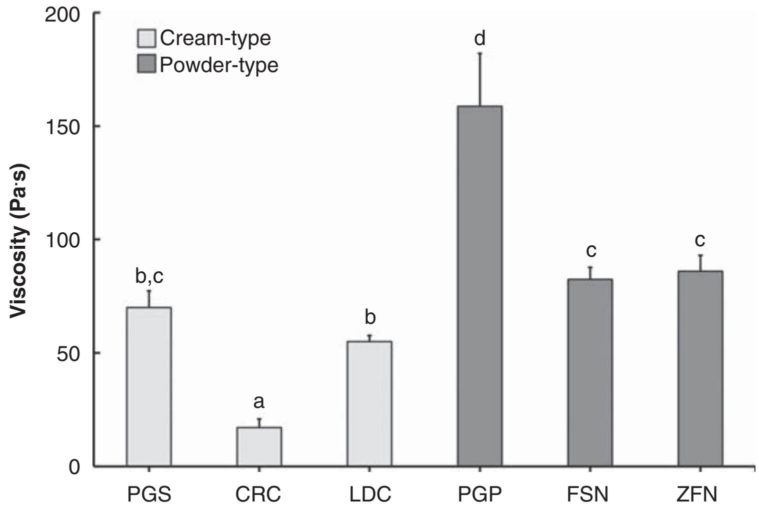

Figure 3. Mean initial viscosity with standard deviation. Viscosity of cream-type adhesives was lower than the powder-type adhesives. Identical letters indicate no significant differences ($p > 0.05$, SNK test).

Table II. Mean adhesive strength of commercial denture adhesives before and after immersion.

	Adhesive strength (kPa ± SD)						
Materials	0 min*	1 min*	10 min*	30 min*	60 min*	180 min*	360 min*
PGS	45.03 ± 6.07	103.38 ± 7.42	111.38 ± 3.86	112.08 ± 20.49	115.49 ± 4.13	104.94 ± 6.39	61.24 ± 10.62
CRC	51.66 ± 5.00	132.50 ± 10.28	117.26 ± 9.20	131.55 ± 4.68	123.39 ± 4.09	115.47 ± 10.72	46.83 ± 2.20
LDC	56.31 ± 9.82	109.84 ± 12.41	126.48 ± 6.46	100.87 ± 6.23	123.90 ± 2.64	121.11 ± 13.60	76.26 ± 19.80
PGP	82.05 ± 10.51	79.82 ± 9.85	90.75 ± 8.12	87.28 ± 11.33	92.32 ± 11.14	43.52 ± 4.21	
FSN	94.98 ± 4.91	65.43 ± 9.07	83.26 ± 9.07	65.61 ± 0.92	71.62 ± 12.45	49.86 ± 7.92	
ZFN	60.68 ± 11.48	83.14 ± 6.81	86.50 ± 7.37	77.59 ± 10.19	90.03 ± 7.37	57.09 ± 4.28	

*Immersion time.
SD, standard deviation.

different materials ($p < 0.05$, ANOVA). The initial viscosity of all the cream-type adhesives was lower than the powder-type adhesives ($p < 0.05$, ANOVA). PGP had the highest viscosity, while CRC had the lowest initial viscosity ($p < 0.05$, SNK test).

Table II shows the variation in adhesive strength of the tested materials according to immersion time. The ANOVA results indicate significant differences among the tested materials and reveal significant effects of immersion time on adhesive strength (Table III). Before immersion in water, all the powder-type denture adhesives exhibited higher adhesive strength than the cream-type denture adhesives. However, the adhesive strength of cream-type denture adhesives

Table III. Two-way ANOVA for adhesive strength of materials.

Source of variation	Sum of squares	df	Mean squares	F	Sig
Corrected model	244,541.69[a]	41	5,964.431	65.201	0.000
Intercept	1,415,615.26	1	1,415,615.26	15,475.011	0.000
Materials	65,304.212	5	13,060.842	142.777	0.000
Times	124,492.782	6	20,748.797	226.819	0.000
Materials & times	54,744.696	30	1,824.823	19.948	0.000
Error	15,368.219	168	91.477		
Total	1,675,525.17	210			
Corrected total	259,909.908	209			

[a] $R^2 = 0.941$.

increased significantly with immersion, achieving higher adhesive strength than powder-type denture adhesives. The adhesive strength of all the tested materials sharply increased after immersion in water and then decreased over time. For powder-type adhesives, the adhesive strength significantly decreased after immersion in water for 60 min, while the adhesive strength of cream-type adhesives significantly decreased after immersion in water for 180 min. Powder-type denture adhesives were completely dissolved after 360 min, so the adhesive strength was unable to be measured at the 360 min time point.

Discussion

The null hypothesis that the adhesive strength of cream-type denture adhesives lasts longer than powder-type denture adhesives was unable to be rejected. When adhesives are placed in the mouth, they become viscous and sticky due to water absorption by the water soluble polymer [18]. Denture adhesives act by producing a highly viscous layer between the denture and its supporting tissues [13]. The high viscosity is necessary for retention [19]. However, high viscosity reduces the ease of manipulation and causes problems with hygiene [13]. An ideal denture adhesive should possess a low initial viscosity, which allows easy manipulation, followed by high viscosity to maximize retention [19]. The initial viscosity of the three cream-type denture adhesives was lower than all the powder-type denture adhesives. In this study, powder-type denture adhesive samples were prepared by mixing powder with distilled water. Therefore, dissolution reaction of water-soluble polymer is already begun in this type of materials. This may explain why the initial viscosity of powder-type denture adhesives is higher than cream-type denture adhesives. Similarly the adhesive strength of cream-type denture adhesives was lower than the powder-type adhesives before immersion in water. In the present study, we measured only the initial viscosity and did not measure the viscosity over time. In the initial viscosity of powder-type materials, PGP showed highest value than the other two materials. The main components of PGP are the CMC and PVM-MA (Table I). CMC has higher solubility and provides a strong initial hold, but it dissolves quickly within a relatively short period [21]. This is the reason that showed the result mentioned above. Other differences between the initial viscosity of cream-type denture adhesives may be due to variations in the type and content of active ingredients used.

Our findings suggest that cream-type denture adhesives are more effective than powder-type adhesives because of their lower initial viscosity and higher adhesive strength. CMC and PVM-MA are often used as active ingredients in denture adhesives, especially in cream-type adhesives, which are designed to achieve both short-term and long-term effectiveness [14]. CMC has higher solubility and provides a strong initial hold, but it dissolves quickly and loses its effectiveness within a relatively short period. PVM-MA is less soluble, allowing it to play a positive role later and last for longer [21]. This effect can be observed in Table II, which demonstrates that the cream-type materials had a higher initial strength and their high adhesive strength lasted longer than powder-type materials after immersion in water.

However, powder type adhesives may have better manipulation properties and greater efficacy during application. These results are consistent with earlier studies. Chew [23] reported that cream-type denture adhesives were significantly more effective in improving the retention between an acrylic disc and rat skin than powder and seat-type denture adhesives. Polyzois et al. [24] using gnathodynamometry and Kalra et al. [25] using pressure transducers, evaluated the effects of three types of denture adhesives (paste, powder, strips) on the incisal bite force of maxillary dentures. The results indicated that the incisal bite force was significantly higher for the paste adhesive, followed by the powder adhesive, adhesive strips and no adhesive, in both well-fitting and ill-fitting dentures [24]. These results are also supported by Uysal et al. [26] and Kulak et al. [27]. Dental professionals are most likely to recommend a cream-type denture adhesive.

In addition to cream-type and cushion-type denture adhesives adhesives, cushion-type adhesives have also become available. Cushion-type denture adhesives have greater initial viscosity according to our unpublished data, with the highest initial viscosity reaching 1121 Pa·s, making manipulation difficult. Koronis et al. [17] investigated three cushion-type denture adhesives and found them to be effective in improving patient satisfaction and masticatory ability; however, the dental professional should not neglect the risk of alveolar bone resorption caused by inappropriate use of home reliners (cushion-type denture adhesives) [28,29]. Good instruction from a dental professional and careful attention to the manufacturer's instructions are very important when using cushion-type denture adhesives.

Although denture adhesives can provide many advantages for patients, there has been an ongoing focus on their side-effects. Several cases have been reported of deformation of the mandibular alveolar ridge caused by inappropriate use of home reliners [28,29]. Recently, concerns have been raised about the adverse systemic effects of denture adhesives, with suggestions that excessive zinc ingestion from over-use of denture adhesives causes depression of serum copper, resulting in bone marrow depression and widespread sensory and motor neuropathies [11,30]. It is worth noting that FSN still uses karaya gum as an active ingredient. Karaya gum may induce allergic reactions [31] and aqueous solutions of karaya gum may lower the critical pH of hydroxyapatite and decalcify dental enamel [32,33]. However, we did not measure pH in the present study. Denture patients should use denture adhesives on the advice of their dentists, receiving instruction in their proper use and cautions against misuse, in order to maximize benefits and minimize misuse.

The present study did not completely simulate clinical behavior because the specimens were tested for viscosity in a dry state at 37°C and all adhesive strength tests were conducted in a dry state at 23°C after immersion in distilled water. To overcome the limitations of the *in vitro* tests, artificial saliva should be used as an immersion solution. For a more complete understanding of the relationship between viscosity and adhesive strength, a study should be conducted to assess the influence of thermo-cycling on the viscosity and adhesive strength of denture adhesives. Also the bite force until denture dislodgement should be evaluated when complete denture wearers use denture adhesives.

Our findings indicate that the adhesive strength of denture adhesives fluctuates according to immersion time. Furthermore, the adhesive strength of cream-type denture adhesives lasts longer than powder-type materials. The adhesive strengths of the commercial denture adhesives evaluated in this study after immersion for 60–180 min were in the acceptable range. We suggest that dentists should understand the properties of commercial denture adhesives and should carefully advise patients of suitable choices.

Conclusions

In summary, the results of this study show that cream-type denture adhesives have lower initial viscosity and higher adhesive strength than powder-type denture adhesives, which may have better manipulation properties and increased efficacy during application. From the standpoint of adhesive strength, the commercial denture adhesives evaluated in this study are suitable for use for 60–180 min in clinical situations.

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Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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