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Properties and characteristics of foam denture cleaners as denture adhesive removers

Reiya HORINOUCHI[1]*, Kae HARADA[1]*, Mamoru MURAKAMI[2], Yusuke YAMASHITA[1], Yuji KAMASHITA[1], Naohiro SHIMOTAHIRA[1], Taizo HAMADA[3], Yasuhiro NISHI[1] and Masahiro NISHIMURA[1]

[1] *Department of Oral and Maxillofacial Prosthodontics, Graduate School of Medical and Dental Sciences, Kagoshima University, Kagoshima, Japan*
[2] *Department of Removable Prosthodontics and Implant Dentistry, Advanced Dentistry Center, Kagoshima University Hospital, Kagoshima, Japan*
[3] *Hiroshima University, Hiroshima, Japan*
Corresponding author, Kae HARADA; E-mail: hkae@dent.kagoshima-u.ac.jp

The need for denture adhesives is increasing worldwide, but few denture-care products target denture adhesive users. Foam denture cleaners have been recently marketed to assist brush denture cleaning, but there is a lack of objective evaluation. In this study, we compared the detergency of denture adhesives using six commercial foam-denture cleaners. For removing the adhesives, most of the tested cleaners were effective in immersion experiments, and three cleaners were more effective in the denture cleaning experiment compared to control water. However, only one could effectively remove the slime that is derived from the adhesive and detergency of artificial dirt. The surface roughnesses of the denture base and the relining material revealed that prolonged immersion in some cleaners could be affected. The results suggest that different commercial foam denture cleaners have different detergency levels, and that some cleaners may affect the properties of denture materials upon long-term use.

Keywords: Denture cleaner, Denture adhesive, Oral health care, Denture cleaning

INTRODUCTION

The importance of dentures and denture hygiene is increasing in ageing and aged societies[1-3] as the age of the population is increasing rapidly around the world[4]. Many denture wearers use denture adhesives to compensate for the stability of incompatible dentures and to enhance masticatory function[3,5-8] due to their difficulty accepting professional maintenance for various reasons. However, there are notable drawbacks in terms of the difficulty associated with removing adhesives from dentures after use. Mechanical denture cleaning with a brush or chemical cleaning with commercially available denture cleaners can reduce plaque on denture surface, which consists of oral microorganisms[8-10]; however, these methods are not sufficiently effective in removing the adhesive from the denture surface[11-13]. Insufficient cleaning of dentures may provide a reservoir for pathogens, which could induce denture stomatitis, periodontitis, caries, pneumonia, gastrointestinal infection, and pleural infection[14-17]. Denture adhesive residue is not only uncomfortable for users but may also influence the formation of denture plaque[18]. Recently, wipe sheets (Polident dry wipe and Polident Cleansing Wipes, GSK, Brentford, UK)[19] have been marketed; however, there are not enough reported evaluations of these products. Thus, there is a clinical need for technologies that simplify oral care for the older adults, including denture adhesive removal, and developmental research on the simplification of the oral care of denture adhesive users is insufficient.

Denture cleaners are classified by their active ingredients or properties[20,21]. In terms of property, they can be categorized into paste and immersion types, and immersion cleaners can be further classified into tablet, powder, liquid, *etc.*, based on their properties. Foam cleaners packaged in foam pump dispensers, which have recently been added and marketed, are used to improve the cleaning effects of mechanical denture brushing. Denture cleaners can remove plaque from denture surfaces created by food residue and bacteria after denture use[22]; however, foam denture cleaners have not been on the market for a long time, and the properties of these products remain largely unknown. In addition, no products have been found to be sufficiently effective in removing denture adhesives. Harada-Hada *et al*. reported that hydrophilic (insoluble) ingredients in commercially available cream denture adhesives, such as liquid paraffin and petrolatum, could make their removal from dentures difficult[11,12], and surfactants with hydrophilic-lipophilic balance (HLB) values of 10.5 and 13.5 were found to be effective in the removal of the insoluble components of cream adhesives by their action in four steps: 1. penetration; 2. adsorption; 3. emulsification and solubilization; and 4. emulsion[23]. This finding led to the development of a foam denture cleaner Dentro Clean Mousse (DCM; Dentronics, Tokyo, Japan), which is the first commercially available denture adhesive remover[24].

In this study, we investigated the effectiveness of the commercially available foam denture cleaners in the removal of denture adhesives and oily dirt from acrylic resin materials, as well as their effects on the surface properties of denture materials. Our results provide new insight into the detergency and effects on denture materials of foam denture cleaners, which is valuable for

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denture adhesive users.

MATERIALS AND METHODS

Denture adhesives and denture cleaners

We prepared two cream adhesives and six foam denture cleaners, as listed in Table 1.

Removal assay of cream denture adhesives from acrylic resin materials

The removal assay of cream denture adhesives from acrylic resin materials was performed as previously described[23]. Briefly, denture adhesives (Poligrip [PG] and Though Grip [TG]) stained with 0.2% Oil Red (w/w; FUJIFILM Wako Pure Chemical, Osaka, Japan) were spread on one side of transparent acrylic resin plates (Comoglas, Kuraray, Tokyo, Japan) using φ7.5-mm molds composed of glass films. The plates on which the denture adhesives were spread were immersed in undiluted solutions of the foam denture cleaners and control water for 6, 12, and 24 h at 23±2°C. As previously described, the area covered by red adhesive residue was scored on a scale of 0–5 (score 5, 100%; score 4, 76%–99%; score 3, 51%–75%; score 2, 26%–50%; score 1, 1%–25%; and score 0, 0% red area)[12,23]. After the immersion, the residual areas of denture adhesives were visually determined as the percentages of the denture adhesive-spread area before immersion and scored. The mean scores from were calculated from the results of five experiments (n=5).

Removability of denture adhesives and slime from denture surfaces

A discarded denture was used in the experiment after sterilization by autoclaving. PG (0.5±0.05 g) stained with Oil red O was spread on the mucosal surface of the denture by a finger, followed by immersion in tap water at 23±2°C for 5 min to soften the adhesives. After immersion, the foam of denture cleaner was applied to the denture mucous surface with two pushes, and the entire mucosal denture surface was rubbed uniformly for 20 strokes with a denture brush (Sunstar, Osaka, Japan), followed by an additional 20 strokes under running water adjusted to a constant flow rate. The control was cleaned by scrubbing for 20 strokes without any foam denture cleaner, followed by another 20 strokes under running water. The denture was shaken once to remove the remaining solution from the surface. The procedures of applying and washing denture adhesives were performed three times, and we scored the detergency of the denture adhesives and the slime from the adhesive residue on the mucosal surface of the denture as shown in Table 2. The experiments were performed by five evaluators, and the mean scores were calculated (n=5).

Removal assay of artificial oily dirt from acrylic resin

Removal assays of artificial oily dirt from the acrylic resin were performed. Artificial oily dirt was prepared as described previously with minor modification, as often done in the detergency tests for commercial household detergents[25,26]. The dirt was prepared from beef tallow oil (Yamakei Industiral, Osaka, Japan), soybean oil (Yamakei Industiral), monoolein (FUJIFILM Wako Pure Chemical), Oil red (FUJIFILM Wako Pure Chemical), and chloroform. Then, 3 μL of oily dirt was spread on each transparent acrylic resin plate and dried at room temperature overnight. The resin plates were immersed in the solutions or water control and maintained at 23±2°C for 1, 3, 6, 12, and 24 h. After immersion, the

Table 1 Details of the denture adhesives and cleaners tested

	Material	Code	Manufacturer
Adhesives	Poligrip	PG	GlaxoSmithKline K.K., Tokyo, Japan
	Tough Grip Cream	TG	Kobayashi Pharmaceutical, Osaka, Japan
Cleaners	Ci Foam Freshener	CIF	Ci Medical, Ishikawa, Japan
	Dent Mousse	DEM	Bee Brand Medico Dental, Osaka, Japan
	Dentro Clean Mousse	DCM	Dentronics, Tokyo, Japan
	Partial Dent Cleaning Foam	PAC	Kobayashi Pharmaceutical
	Pica Awa Cool	PIC	Rohto Pharmaceutical, Osaka, Japan
	Polident Fresh Cleanse	POF	GlaxoSmithKline K.K.

Table 2 Scores describing the removability of denture adhesive and slime from denture surfaces

Score	Evaluation of removability
3	Very effective
2	Effective
1	Slightly effective
0	No effect

sample plates were removed from the solutions and shaken once to remove the remaining solution from the surface, and the residual dirt on the acrylic plates was checked. The mean times at which the dirt remained were calculated from five experiments (n=5).

Measurement of the surface roughness of a denture base and denture lining material

Firstly, plates of dimensions 10×10×2 mm were prepared from a denture base resin (GC Acron, GC, Tokyo, Japan) and denture lining material (Kurarebase,

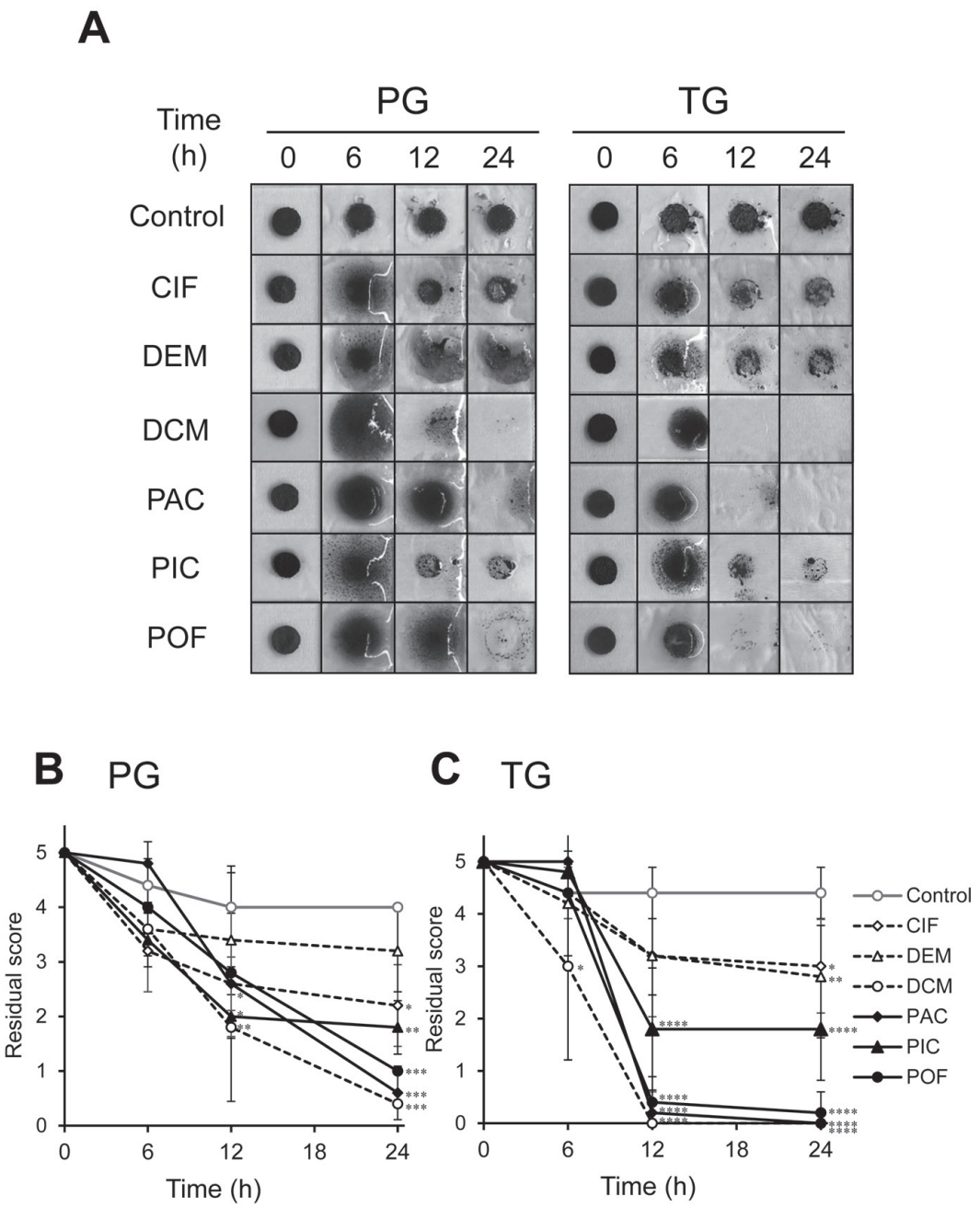

Fig. 1 Removability of denture adhesives from acrylic resin after immersion in solutions of foam denture cleaners.
A: Detachment of the denture adhesive [Poligrip (PG, right panels) and Tough Grip Cream (TG, left panels)] after immersion in undiluted solutions of denture cleaners and control water. The images show representative sample plates before and after 6, 12, and 24 h of immersion. B and C: PG (B) and TG (C) residue values after immersion in cleaners and with the control. The graphs represent the mean±SD (n=5). *p<0.05, **p<0.01, ***p<0.001, ****p<0.0001: compared with control water.

Kuraray Noritake Dental, Tokyo, Japan). The surface roughness of plates was equalized by polishing with #1500 waterproof sandpaper. The specimens were immersed in undiluted foam denture cleaner solutions or control water at 23±2°C. The surface roughnesses (R_a) of the resin plates were measured using a surface texture measuring instrument (SURFCOM130A, Tokyo Seimitsu, Tokyo, Japan) after immersion for seven days. The measurements were performed five times for each plate, and the calculated mean of R_a was considered the result of the experiment. The experiments were

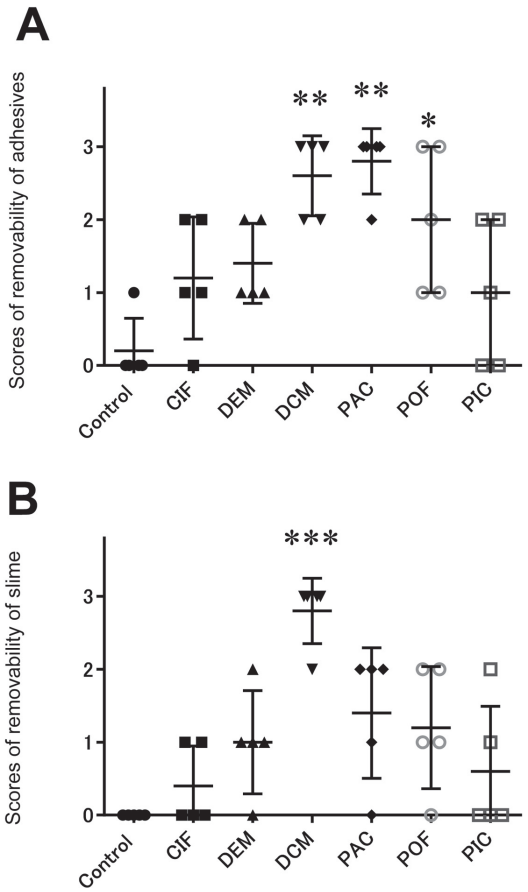

Fig. 2 Removability of denture adhesive and slime from denture surfaces.
A and B: The mean score for each foam denture cleaner obtained from the evaluators is represented in the graphs (n=5). Error bars indicate standard deviations (n=5). *p<0.05, **p<0.01, ***p<0.001: compared with control water.

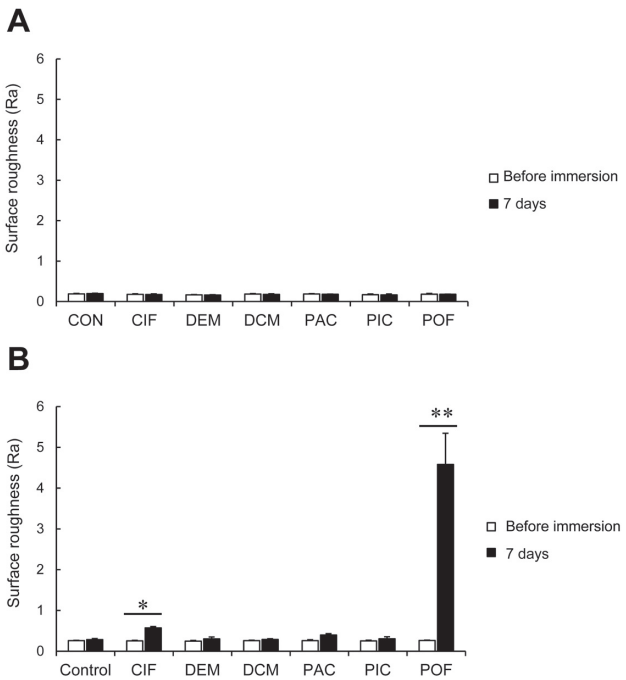

Fig. 3 Effects of foam denture cleaners on the surface roughness of denture relining material and denture base resin.
A: Effects of the immersion in foam denture cleaners on the surface roughness of the denture base resin (n=5). B: Effects of immersion in foam denture cleaners on the surface properties of the denture relining material (n=5). *p<0.05, **p<0.01: compared with before immersion.

Table 3 Remaining time of artificial dirt spots after immersion in denture cleaners

Denture cleaner	Mean of remaining time (h)	p value (*vs.* control)
Control	24	—
CIF	24	>0.9999
DEM	21.4±6.30	0.7212
DCM	2.50±1.75	<0.0001****
PAR	24	>0.9999
PIC	24	>0.9999
POF	20.6±5.42	0.1495

**** p<0.0001 compared with control, n=5

performed three times, and the means of R_a were calculated.

Statistical analyses

The repeated measurement two-way ANOVA with Dunnett's multiple comparisons was performed for to analyze the denture adhesive removal (Figs. 1A–C). For checking the normality of the residual score of the denture adhesives or the slime on the denture and the remaining time of adhesive, the Shapiro-Wilk tests was performed, and Kruskal-Wallis tests with Dunn's multiple comparisons were also performed (Figs. 2A, B and Table 3). The surface roughnesses was analyzed using the repeated measurement two-way ANOVA with Bonferroni's multiple comparisons (Fig. 3). A p value of <0.05 was considered statistically significant in the multiple comparisons. Here, the values *p>0.05, **p>0.01, ***p>0.001, and ****p>0.001 in the figures and tables indicate statistical significance. Our data are presented as mean±standard deviation (SD).

RESULTS

To examine the original detergency of cream denture adhesives by the foam denture cleaners without any mechanical cleaning, we performed immersion experiments in undiluted solutions of the foam-denture cleaners using transparent acrylic resin plates. As shown in Fig. 1A, PG was almost completely removed by DCM, PAC, and POF after immersion for 24 h. TG removal occurred earlier than that of PG, where the former was completely removed by DCM and almost completely removed by PAC and POF after 12 h and the latter was completely removed by DCM and PAC and almost completely removed by POF after 24 h. Large areas of staining removed in the CIF, DEM, and PIC cases even after immersion for 24 h. As shown in Fig. 1B, the PG residue scores of the six cleaners were not different from that of control water at 6 h, however, DCM, CIF, and PIC scored lower than the control at 12 h (DCM: **p<0.01; CIF, PIC: *p<0.05 *vs.* control water at 12 h, n=5), and DCM, POF, PAC, CIF, and PIC scored lower than the control at 24 h (DCM, POF, PAC: ***p<0.001; PIC: **p<0.01; CIF: *p<0.05 *vs.* control water at 24 h, n=5). Meanwhile, the TG residue scores were lower in DCM at 6 h (Fig. 1C, *p<0.05 *vs.* control water at 6 h, n=5); DCM, POF, PAC, PIC scored lower at 12 (****p<0.001 *vs.* control water at 12 h, n=5), and the scores of all the six cleaners were lower than those of control at 24 h (DCM, POF, PAC, and PIC: ****p<0.001; DEM: **p<0.01; CIF: *p<0.05 *vs.* control water at 24 h, n=5).

We examined the removal of the denture adhesives when the dentures were cleaned with a foam denture cleaner with denture brushes in a manner consistent with a designed protocol. As shown in Fig. 2A, the adhesive residue scores of DCM, PAC and POF were significantly lower than that of control water (DCM and PAC: **p<0.01; POF: *p<0.05 *vs.* control water, n=5). For other denture cleaners, the score means were lower than that of the control water although no significant differences were observed (p>0.05, *vs.* control water, n=5). We evaluated whether the slime from the denture adhesive that remained in a miniscule quantity could be visually confirmed after washing, finding that only DCM had a lower slime score than that of the control (Fig. 2B, ***p<0.001 DCM *vs.* control water, n=5).

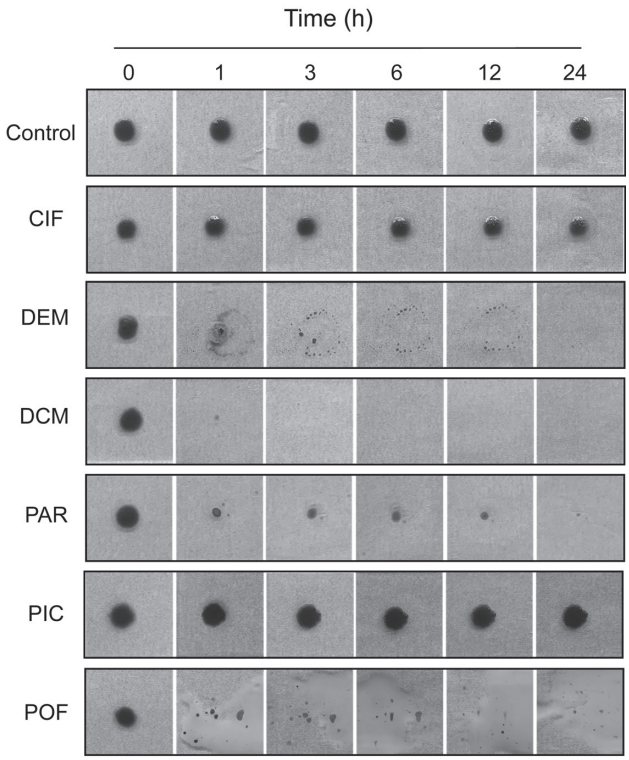

Fig. 4 Removability of oily dirt from acrylic resin after immersion in solutions of foam denture cleaners. Images show representative transparent resin plates on which artificial oily dirt was spread before and after 1, 3, 6, 12, and 24 h of immersion in cleaner solutions and control water (n=5).

To examine the detergency in cleaning food-derived stains, which are among the main targets for denture cleaners to remove, we also performed experiments with artificial dirt stains, which are frequently conducted when testing household cleaners[25,26]. As shown in Fig. 4, the spots of oily dirt began to be removed at 1 h by DEM, DCM, PAR, PIC, and POF. The dirt was completely removed by DCM immersion for 3 h, whereas the other spots were not. We calculated the times at which the spots remained, and only DCM showed a significant reduction in remaining time by immersion compared to the water control (Table 3, ****p<0.0001 DCM *vs.* control water, n=5).

To evaluate whether the foam denture cleaners could affect the surface roughnesses of denture materials, we compared the surface roughness measurements of denture materials before and after immersion in the cleaner solutions. As demonstrated by Fig. 3A, there are no significant differences in the R_a of the surface of

the denture base material (GC Acron) between before and after immersion in the foam denture cleaners (n=5). However, the R_a of the denture lining material (Kurarebase) after immersion in POF for a day and immersion in CIF and POF for 7 days was significantly larger than that of the control, although there were no significant differences between those before and after the immersion in DEM, DCM, PAC, or PIC (Fig. 3B, CIF: *p<0.05 7 days *vs.* before immersion; POF: **p<0.01, 7 days *vs.* before immersion, n=5).

DISCUSSION

Inadequate removal of denture adhesives and the use of unsanitary dentures could increase the risk of oral contamination, which could induce denture stomatitis, aspiration pneumonia, or other systemic diseases[14,15,17]. The primary purposes of denture cleaners are to remove dirt and stains from dentures, mostly denture plaque of bacterial origin and stains and debris from food and beverages[22]. In this study, we analyzed newly commercialized foam denture cleaners, including the denture adhesive remover DCM, in terms of detergency of cream denture adhesives and oily dirt spots as experimental food dirt, as well as the effects on the surface properties of denture materials.

Effects of immersion of foam denture cleaners on removing denture adhesives

In the immersion experiment of the undiluted cleaner solutions, the removal of PG and TG was observed as the immersion time passed compared with the control water (Fig. 1A). For PG removal, CIF, DCM, and PAC at 12 h, and CIF, DCM, PAC, POF, and PIC at 24 h were significantly effective (Fig. 1B). For TG removal, DCM at 6 h, DCM, PAC, POF and PIC at 12 h, and all the tested cleaners at 24 h, were effective (Fig. 1C). In general, the action of surfactants in removing stain or dirt can be divided into four steps (penetration, adsorption, emulsification/solubilization, and emulsion). The surfactant surrounds the stain/dirt and creates micro micelles containing the dirt, which are dissolved in the solution, thus removing the dirt[27,28]. For a seamless functioning against the denture adhesive on the denture, the surfactants suitable for affinity for both the water surrounding the denture and the insoluble components of the adhesives must be used, and these values were determined using the HLB value of 10.5–13.5[23]. The results suggest that the surfactants in DCM with appropriate HLB values helped remove cream denture adhesives as seen in the previous study. In addition, it indicates that cleaners other than DMC can also effectively remove adhesives, suggesting that they also might contain surfactants with appropriate HLB values for removing the adhesives.

Effects of clinical method using foam denture cleaners on the removal of denture adhesives and slime from denture surfaces

In the cleaning experiment using dentures and denture-cleaning brushes, PG was sufficiently removed by DEM, PAC and POF according to visual judgment; only DCM could remove the slime from the adhesive PG (Figs. 2A and B). These results indicate that the PAC and POF as well as DCM can help remove adhesives in a clinical method, but they suggest that only DCM could completely remove residues, including the minute adhesive residue at levels that could not be visually confirmed, which causes denture slime. Furthermore, the results indicate that PAC and POF have the ability to remove the adhesive, but the DCM is specifically effective.

Effects of immersion of foam denture adhesives on artificial oily dirt

The spots of artificial oily dirt were also examined; the remaining immersion time was shorter for DCM than that for the control water (Table 3 and Fig. 4). This result is consistent with those of surfactants with HLB values of 10.5–13.5, and they were suitable not only for cream denture adhesives but also for removing artificial dirt[23], suggesting that the surfactants contained in the DCM could constitute removing effects.

Measurement of foam denture cleaners on the surface of denture materials

The effects on the surface properties of the denture materials were investigated. There were no significant effects on the denture base material (Fig. 3A), and the surface roughnesses of the denture lining material were increased after of 7 day-immersion in POF and CIF; other foam cleaners had no effect after immersion (Fig. 3B). Immersing dentures in the foam cleaner solution is not the intended use; we did not investigate the effects on denture materials in actual clinical usage in the present research. However, the long-term use might affect the denture hygiene because the denture surface roughness can also affect the adhesion of pathogens including *Candida*, which increase the risk of denture stomatitis and other pathogenic microorganisms[29-32]. For relined denture users, it may be necessary to remind not to leave POF or CIF foam on dentures for a long time, as well as to rinse the dentures well immediately after cleaning them, as recommended for the users of general foam denture cleaners.

Our results suggest that some foam denture cleaners are effective in removing denture adhesive dirt from the dentures, and this is the first report to describe the evaluation of foam denture cleaners. However, this study has a few limitations. First, the results of the immersion experiment of the acrylic resin plates and the removal experiment with the denture are not entirely correlated. This may be because the former examined the chemical detergency of the cleaners, and the latter may affect other factors, such as the differences in the removability during mechanical cleaning *via* brushing, in addition to the chemical detergency. Second, we did not examine the actual clinical anti-pathogen properties related to the removability of denture plaque, which is one of the main purposes of denture cleaning, although we confirmed the anti-Candida property of all the cleaners tested by calculating the minimum inhibitory

concentration of some pathogens, including *Candida albicans in vitro* (data not shown). In the future, it is necessary to investigate whether these cleaners are effective in removing *Candida* plaque *in vitro* or *in vitro* and to perform other studies, including clinical research. Third, denture cleaners are used not only to remove plaque from oral bacteria, but also to remove staining, which was not investigated in this study. Foam denture cleaners have only recently been released and have not been sufficiently studied; therefore, there may be more issues to consider in the future. Forth, cream denture adhesives can easily remain on the oral mucosa and provide a platform for oral bacteria to grow[11,33]. Older people tend to have dry mouths due to the side effects of medication and atrophy of the salivary glands[34,35], making it easier for denture adhesives to remain in the mouth. Numerous denture-adhesive users are older adults, and many have difficulty with complicated self-care[36]. The denture adhesives in the mouth cannot be easily removed by rinsing alone, and instead, they require mechanical cleaning, such as wiping with a sponge brush or gauze; cleaning of denture adhesive residues in the mouth is a persistent issue.

Some characteristics of foam denture cleaners were clarified in this study. However, most denture adhesive users have difficulty assessing the complicated condition of the oral cavity, denture characteristics, and denture adhesive usage as well as choosing appropriate denture cleaners based on their characteristics. Therefore, it is important for dental professionals to provide proper diagnoses of the conditions and characteristics of patients and to advise them on the appropriate selection of denture cleaners and denture cleaning methods.

CONCLUSION

The six foam cleaners investigated in this study effectively removed adhesives from cream dentures. However, the strength of the effect varied among the cleaners, with DCM being the most effective and effective in removing artificial dirt. Some foam denture cleaners need to be rinsed under running water immediately after use according to the manufacturer's recommendations to avoid prolonged contact with the foam and to avoid damage to denture materials.

CONFLICT OF INTEREST

Kagoshima University applied for a patent (application number: JP 2018-088831) on a new denture cleaning method. Kae Harada and Masahiro Nishimura are the inventors of this patent. The other authors have no conflicts of interest directly relevant to the content of this article.

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