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Effects of Thermocycling on the Tensile Bond Strength of Three Permanent Soft Denture Liners

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Abstract

Purpose: This study investigated the effect of in vitro accelerated aging reproduced with thermocycling on the bond strength of three commercially available permanent denture soft liners (PermaSoft, Dentuflex, Ufi-gel) with one heat-polymerized polymethyl methacrylate resin denture base (QC-20) by tensile test.
Material and Methods: Ten specimens were prepared for control and test groups of each material for a total of 60 specimens. All controls were stored in water (37°C) for 24 hours before testing. All test groups received 3000 thermal cycles consisting of 1 minute at 5°C and 1 minute at 65°C. All specimens were submitted to a tensile test using a universal testing machine at a crosshead speed of 5 mm/min. Results were statistically analyzed (ANOVA, $p \leq 0.05$, Tukey's post-hoc test).
Results: The mean bond strength of control specimens was (MPa): 0.32 (Ufi-gel), 0.49 (PermaSoft), and 1.19 (Dentuflex). There was no statistical difference ($p > 0.05$) between Ufi-gel and PermaSoft, but both were statistically different ($p < 0.05$) when compared to Dentuflex. After thermocycling, the mean bond strength was (MPa): 0.18 (Ufi-gel), 0.81 (PermaSoft), and 3.32 (Dentuflex). All materials were statistically different ($p < 0.05$). Ufi-gel had the lowest value and Dentuflex the highest in both control and test groups. Dentuflex presented only adhesive failure; in the remaining groups, there was no predominant failure mode, except Ufi-gel control with no adhesive failure.
Conclusions: Despite presenting greater bond strength, thermocycling had a deleterious effect in Dentuflex; Ufi-gel may be adequate for short-term use.

Clinical benefits of resilient soft denture liners have been recognized in prosthodontics for many years. They provide comfort for patients who cannot tolerate occlusal pressures, or who present alveolar ridge resorption, chronic soreness, and knife-edge ridges.[1-3] Liners act as a cushion for the denture-bearing tissues by absorbing and redistributing forces transmitted to the stress-bearing areas of the edentulous ridges.[4,5] Additional uses of soft denture liners have emerged in the last few years for transitional prostheses after implant surgery.[6,7]

Today, several commercial forms are available in plasticized acrylic resins and silicone elastomers.[6,8] Both exist in heat- and autopolymerized forms. Acrylic resin materials generally consist of powder (acrylic polymers and copolymers) and liquid (acrylic monomer and plasticizers: ethyl alcohol and/or ethyl acetate—responsible for material softness).[9] Plasticized polymethyl methacrylate (PMMA) and PMMA denture base materials are similar in chemical structure and so bonding agents are considered unnecessary for these materials.

Silicone resilient lining materials are similar in composition to silicone impression materials. Both are dimethylsiloxane polymers. Polydimethylsiloxane is a viscous liquid that can be cross-linked to form a rubber with good elastic properties. Softness of these liners is controlled by the amount of cross-linking in the rubber, and no plasticizer is necessary to produce a softening effect.[9-11] As silicone liners have little or no chemical adhesion to PMMA resins, an adhesive is supplied to aid in bonding the liner to the resin denture base. Silicone liners keep their softness for a longer period than acrylic resin liners.[12]

Conversely, there are a number of disadvantages to the use of permanent denture soft liners, including loss of

Table 1 Commercial name, material, components, manufacturer, and lot number of materials

Brand	Material	Components	Manufacturer	Lot N°
PermaSoft*	Cold-cured acrylic resin	Powder, liquid, and sealer†	Myerson, Austenal Division, Harrow, UK	049051
Dentuflex*	Cold-cured acrylic resin	Powder and liquid	Dental Medrano, Buenos Aires, Argentina	51402
Ufi-gel‡	Cold-cured silicone	Base and catalyst pastes bonding liquid,§ and glaze	Voco GmbH, Cuxhaven, Germany	08345
QC-20¶	Conventional heat-cured acrylic resin	Powder and liquid	Dentsply International, Inc., Milford, DE	57868

*10 cc powder, 4 cc liquid.
†Sealer was applied in two coats with a 2 minute drying time between coats.
‡Same proportions of pastes (base and catalyst).
§Bonding agents were applied in one coat to the PMMA blocks.
¶21 cc powder, 7 ml liquid.

softness, colonization by *Candida albicans*, porosity, and poor tear strength.[10,13,14] Leaching of plasticizers is responsible for hardening over time during clinical use,[10] when liners are immersed in saliva or stored in water or an aqueous cleansing solution. A common clinical occurrence and major problem is lack of durable bond to the denture.[7] Sufficient bond strength between the soft lining material and acrylic resin denture base is required to avoid interfacial separation at the denture borders. Adhesive failure between the lining material and denture base can create an environment for potential bacterial growth and accelerated breakdown of the soft lining material.[9,15,16] Therefore, the measurement of bond strength is very important.

The bond properties of soft denture liners have been evaluated using tensile strength and tensile, tear, and peeling tests. Numerous investigators evaluated bond strength of resilient liners after accelerated aging by thermocycling.[9] Thermocycling has been shown in many studies to alter bond strength between a resilient liner and acrylic resin denture base. Al-Athel et al[15] found lower bond strength values in silicone lining materials after thermocycling (1.72 and 1.46 Nmm^{-2}), and Pinto et al[9] found no difference in the acrylic resin lining material (0.61 and 0.52 MPa). Kulak-Ozkan et al[17] found higher bond strength in silicone lining materials after thermocycling (6.6 and 8.9 kg/cm^2 before and after the test, respectively).

The aim of the present study was to investigate the effect of in vitro accelerated aging reproduced with thermocycling on the bond strength of three commercially available permanent soft denture liners and one heat-polymerized PMMA resin denture base by tensile test.

Materials and methods

Three permanent soft denture liners (PermaSoft, Dentuflex, Ufi-gel) and a conventional heat-cured acrylic resin (QC-20) were chosen (Table 1). Twenty specimens of each lining material were prepared as follows: a soft denture liner was placed between two 40 × 10 × 10 mm^3 acrylic resin blocks. Bond strength was measured in control specimens 24 hours after processing (37°C) and in test groups after thermocycling.

PMMA specimens were prepared by investing brass dies with a 3-mm thick spacer in a denture flask. Dies and spacers were invested in hard but flexible silicone rubber (Zetalabor; Zhermack, Badia Polesine, Rovigo, Italy) to allow for easy removal of the processed specimens from the flask. All dies and spacers were machined to the same dimensions to standardize PMMA shape and soft denture liner thickness. Acrylic resin was mixed, packed into a mold with a brass spacer, and processed in a water bath at 75°C for 9 hours. After heat-polymerization, the brass spacer was removed from the mold, the PMMA resin specimens were trimmed, and the surfaces to be bonded were smoothed. PMMA specimens were returned to the molds, and denture soft liners were packed into the space made by the brass spacer, trial-packed, and chemically polymerized according to the manufacturers' directions (Table 1).

After polymerization, specimens were removed from the flask and trimmed with a sharp blade. Specimens were equally divided into test and control groups. Each test group, consisting of 10 specimens per soft lining material, received 3000 thermal cycles (MCT 2 AMM Instrumental; Erios, São Paulo, Brazil) at intervals of 1 minute at 5°C and 1 minute at 65°C. Instead of thermocycling, the control group was stored in water at 37°C for 24 hours.

For the tensile test, specimens were placed under tension until failure in a universal testing machine (DL-500 MF; EMIC, São José dos Pinhais, Paraná, Brazil), with a crosshead speed of 5 mm/min. A universal joint between specimens and the testing system was used to prevent any torque on specimens during the test by allowing specimens to self-align axially. In accordance with the manufacturer's instructions, calibration was originally made at the factory and maintained through regular servicing. Even so, a pilot test was performed prior to the experiment, and bond strength values obtained were compared to those in the literature to verify the reliability of the equipment. These results, being in accordance with others in the literature, allowed us to certify that the machine was adequately calibrated to perform the test. Pinto et al[16] found similar values for PermaSoft material control after 4000 thermal cycles; Sertgöz et al[4] found similar values for Ufi-gel material.

Data were recorded using the software program Mtest (mechanical testing—EMIC). The computerized system employed

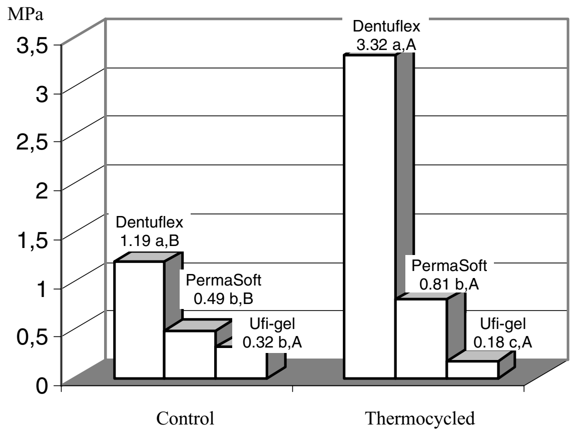

Figure 1 Bond strength of control and thermocycled soft lining materials. (Different lowercase letters indicate statistical differences among materials within groups. Different uppercase letters indicate statistical differences between control and thermocycled values for the same material.)

by the universal testing machine used in the present study dispenses with the necessity of calibration between specimens. The same operator performed all tests to standardize testing conditions for uniformity. Test results were reported in MPa after dividing the load at failure by the geometric cross-sectional area of the bonded surface. After observation, failure was recorded as either cohesive (failure in the soft liner), adhesive (failure of the interface between the denture base and soft liner), or both (mixed mode).

Means and standard deviations were determined for all materials. Group means were compared by ANOVA ($p \leq 0.05$, Tukey's post hoc test) within collections of controls and test materials, and between control and test materials.

Results

Figure 1 presents the bond strengths of the control and test groups. There was no statistical difference ($p > 0.05$) between the control Ufi-gel and PermaSoft, but both were statistically different ($p < 0.05$) when compared to Dentuflex. All materials were statistically different from each other after thermocycling ($p < 0.05$). Regardless of thermocycling, Dentuflex had the strongest bond strength and Ufi-gel the weakest.

Concerning failure type, the Dentuflex group presented adhesive failure regardless of thermocycling. The other groups presented adhesive, cohesive, or both types of failure, regardless of thermocycling, except Ufi-gel control, which presented only cohesive or both adhesive and cohesive failure (Fig 2).

Discussion

In the present study, the thermocycling test followed the study of Pinto et al,[9] who evaluated accelerated aging of resilient liners by thermocycling (3000 cycles) and alternatively immersing specimens for 1 minute in cold and 1 minute in heated water baths. In this type of test, 1000 cycles is probably a reasonable estimate of the maximum extreme temperature changes expected during a year, although some thermocycling could be occurring at a more frequent rate for lower temperature differences. Consequently, 3000 cycles would relate to roughly 3 years of use. Bond strength of selected denture soft liners to a heat-cured PMMA resin was determined by a tensile test, and during the test, axial self-alignment of specimens was ensured.

Dentuflex had the strongest bond strength to the resin denture base in the control group, and the bond strength increased after thermocycling (Fig 1). A high bond strength value could be seen as a positive aspect of the liner, preventing bacterial growth in the interface, allowing for better cleaning, and contributing to comfort and patient health; however, this increase may be an indication that the material became more brittle and probably less viscoelastic.[7] When immersed, soft denture liners undergo two processes: absorption and desorption. Absorption of water and saliva resulting in plasticization of the soft liners and desorption of plasticizers or other soluble constituents would make the material more brittle and apparently stronger.[6,9] The balance between these two processes affects the dimensional stability of the material. These are equally true for the zone at the interface.

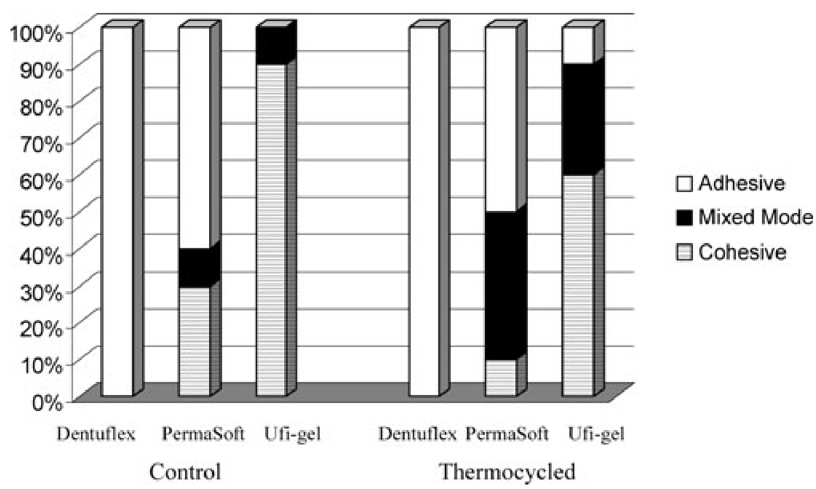

Figure 2 Mode of failure in control and thermocycled soft lining materials.

With this in mind, it can be supposed that after 3 years of simulated use (3000 cycles), this material would lose its softness. It is very important to remember that Dentuflex does not contain a sealer, which would help protect against absorption and desorption. In other words, the material becomes harder, thereby decreasing its cushioning effect.[10,15] Studies involving hardness tests observed Dentuflex to have greater values of Shore A hardness than other soft denture liners. Clinically, this means that among the materials tested, Dentuflex would remain adhered to the acrylic resin for a longer period than the others, but, on the other hand, it would be the first to lose its softness. This fact makes it less desirable for clinical use, because it implies less comfort for the patient. The fast hardening of this material could damage tissues after surgical treatment.

Results from PermaSoft were similar to those found in literature,[6] showing that thermocycling caused an increase in the bond strength (Fig 1). The results of this study contradict Pinto et al[9] who reported no significant difference in PermaSoft bond strength values after thermocycling. This soft denture liner includes a sealer, which probably decreases the level of water absorption and desorption and, consequently, prevents early hardening, thereby increasing the longevity of the material.[9] It could be suggested that PermaSoft keeps its softness longer than Dentuflex. The behavior of these two soft denture liners in the present study may be further explained by their inherent characteristics, such as the concentration of plasticizing agents and/or the effect of sealer. Dentuflex probably has a lower quantity of plasticizing agents than PermaSoft, being more rigid and showing a higher tensile strength. Although both are plasticized acrylic resins, they can show different results due to differences in components' quantity or chemical composition.

According to Kawano et al,[14] a bond strength of 0.44 MPa is acceptable for clinical use of soft denture lining materials. Considering this criterion, results of the present study show that Dentuflex and PermaSoft have satisfactory bond strength, while Ufi-gel liner has unsatisfactory bond strength.

Failure in Dentuflex was 100% adhesive in both control and test groups, implying that the tensile strength of resilient liner was higher than the bond strength to PMMA. All failure types occurred in PermaSoft, indicating equilibrium between adhesion to PMMA and tensile strength of the material.

Ufi-gel liner, a cold-cured silicone lining material, stretched over time and presented the lowest values of bond strength, both in control and thermocycled groups, without significant difference (Fig 1). This liner did not even reach the adequate bond strength score already cited. The same behavior was observed by Aydin et al[2] after 90 days of aging. A silicone liner does not contain a plasticizer; however, it does contain filler.[9] Water absorption by the filler could lead to increased softness when stored in water, resulting in more elasticity, lower bond strength, and cohesive failure.[17] As a silicone-based soft liner does not have chemical adhesion to PMMA, the use of an adhesive is necessary. Therefore, the bond strength depends on the tensile strength of the materials and the adhesive used.

As shown in Figure 2, failure in this lining material was cohesive and mixed (90% and 10%, respectively) for the control group, changing after thermocycling (60%, 30%, and 10%, for cohesive, mixed, and adhesive, respectively). These findings agree with Emmer et al,[7] who found a silicone-based liner with the lowest bond strength (1.21 MPa) and cohesive failure. It could be suggested that thermocycling had a deleterious effect on the interface (lining material/acrylic resin denture base), increasing the adhesive failure; however, it did not affect tensile strength.[4,13]

Besides the adhesive, Ufi-gel comes with a glaze that probably prevents water absorption and desorption, helps maintain softness, and consequently provides more patient comfort. In this way, Ufi-gel is considered adequate for temporary use, but due to its low bond strength, it would need to be replaced after a short period of time.

In this study, the differences in bond strength and modes of failure were valuable for understanding the adhesion characteristics of the soft denture liners studied. It is important to remember that a direct comparison with other studies is very delicate because of the different mechanical tests and research protocols used, such as the temperature variation during the test, the acrylic resin used, and others. The majority of studies concerning thermocycling used 5 and 55°C of temperature variation. Hardness, weight change, tensile strength, tear strength, and color stability are all properties of denture soft liners. Selection of a particular liner cannot be based on any single property.

Conclusions

Within the limitations of the present study, the following can be concluded:

- Dentuflex liner presented the greatest bond strength values, and Ufi-gel the weakest ($p < 0.05$).
- Thermocycling increased bond strength in Dentuflex and PermaSoft liners ($p < 0.05$), but had no effect on Ufi-gel ($p > 0.05$).

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