Bond Strength of Soft Liners to Fiber-Reinforced Denture-Base Resin

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Abstract

Purpose: This study evaluated bond strengths of four soft liners to fiber-reinforced (FR) and unreinforced poly methyl(methacrylate) (PMMA) denture-base resin.
Materials and Methods: The autopolymerized denture-base resin Palapress Vario (Heraus Kulzer GmbH, Hanau, Germany) was used as the substrate ($15 \times 15 \times 5$ mm^3). The test group consisted of substrates reinforced with porous PMMA preimpregnated unidirectional glass fibers (Stick [StickTech, Turku, Finland]) (PMMA + FR group), and the control group was unreinforced acrylic resin (PMMA group) (n = 80 per group). One of four soft liners (Ufi Gel SC [Voco, Cuxhaven, Germany], Sofreliner Tough [Tokuyama Dental Corporation, Tokyo, Japan], Vertex SoftSil 25 [Vertex-Dental B.V., Zeist, The Netherlands], and Eversoft [Dentsply Austenal, York, PA]) was placed and cured between two substrates using a polyethylene ring (10 mm inner radius, 3 mm height). Tensile bond strength tests (crosshead speed = 10 mm/min) were performed, and the results were analyzed using analysis of variance followed by Tukey's test ($p = 0.05$). Fracture surfaces were categorized as adhesive or cohesive-mixed modes, and failure types were statistically analyzed using chi-square test.
Results: FR did not affect the bond strength results significantly ($p > 0.05$) except for Ufi Gel SC. Significant differences in bond strength were found among the reline materials ($p < 0.001$). FR specimens showed a significantly higher number of cohesive-mixed fractures compared to unreinforced specimens ($p < 0.05$), except for plasticized acrylic-based reline material (Eversoft [Dentsply Austenal]), which showed fewer cohesive-mixed failures with FR.
Conclusions: The choice of appropriate reline material system with FR acrylic resin is important for the soft liner/denture-base polymer bond. Glass FR did not have a decreasing effect on the bond strength, except for Ufi Gel SC.

Denture-bearing tissues are not able to withstand the forces transmitted by denture bases for long periods. This ability may be further decreased in the frail elderly. Soft liners are used to distribute the forces more evenly to soft tissues during function of tissue-supported prostheses. The tissue-contacting surfaces of removable dentures and other oral and maxillofacial prostheses are coated with soft liner, and this structure gives comfort to the patient and in certain cases is expected to have a healing effect on the mucosa.[1-4]

For the proper function of a soft liner and adequately long service life, a reliable adhesion to the denture base is required. The difficulty of obtaining a reliable bond between soft relining materials and poly(methyl methacrylate) (PMMA) denture-base polymers has often been discussed in the literature.[5-11] Although patients have welcomed soft relined complete dentures, early fractures due to the reduction of the denture thickness, as a part of the application procedures, is one of the main reasons for failure. To minimize and prevent prosthesis fracture, reinforcement of the dentures would be an alternative.[12-16] Introducing glass fibers to the denture for reinforcement purposes is currently a popular way to improve mechanical properties of denture-base materials. The use of preimpregnated glass fibers are known to increase the flexural properties of the acrylic denture-base resin.[14] Previously, a clinical survey had shown that polymer-preimpregnated glass fiber reinforcement (FR) can be useful in eliminating denture fractures.[12] Therefore, the reinforcement of a removable denture before soft liner application may result in a longer clinical service life, both for the denture and the soft liner, by improving the flexural properties of the denture; however, because of the high glass content at the bonding surface of a reinforced denture, the bond between the denture and the soft liner may be influenced. The effect of the FR on the bond strength of soft liners is not known.

The aim of this study was to evaluate the effect of PMMA-impregnated glass FR of a denture-base acrylic resin on the bond strength of four soft liners. The null hypothesis was that the bond strength between the denture-base acrylic resin and the soft liners would not be affected by the reinforcement.

Materials and methods

The materials used in this study, batch numbers, manufacturers' information, chemical composition, and processing methods are listed in Table 1. Autopolymerizing denture-base resin plates ($15 \times 15 \times 5$ mm^3) were used as substrates ($n = 160$). The plates were polymerized in a mold under 300-kPa pressure at 80°C ± 5°C for 15 minutes in a pressure-curing device (Ivomat Type IP 2, Ivoclar AG, Schaan, Liechtenstein). After polymerization, the plates were divided into two groups ($n = 80$) and received different surface treatments. Porous PMMA-preimpregnated unidirectional glass fiber reinforced (group PMMA-FR) specimens were used for the study group. Before the application of FR to the PMMA-FR group, the porous PMMA reinforcement was wetted with the monomer liquid/polymer powder mixture of Palapress Vario and polymerized, after being placed on top of the already polymerized denture-base resin specimens.[17] The remaining specimens (group PMMA) received no reinforcement and were used for the control group.

All the substrates were then stored in water (37°C) for 1 month before soft reline application. Before application of the liners, the substrates were wet ground with SiC-grinding paper (500 grit, Federation of European Producers of Abrasives [FEPA]) to standardize the bonding surfaces. In the PMMA-FR group, the fibers of the reinforced substrate were longitudinally exposed as a result of the grinding procedure. Thereafter, the proprietary bonding agents were applied, the soft liners were injected into polyethylene rings with a diameter of 10 mm (3 mm height), and substrate plates (PMMA-FR or PMMA) were placed on both sides of the rings (Fig 1A). For each type of substrate/liner combination, ten specimens were made forming four study groups and four control groups. Liners were manufactured according to manufacturer instructions (Table 1), and specimens were stored in water (37°C) for 24 hours before testing. Tensile testing (Fig 1B) was performed on a universal testing machine (Lloyd LRX, Lloyd Instruments Ltd., Fareham, Hampshire, UK) at a crosshead speed of 10 mm/min, and data were collected by a PC using the Nexygen system (Nexygen, Lloyd Instruments Ltd.). Tensile bond strength and percentage elongation (strain at fracture) were calculated automatically using the equations below

$$\sigma = \frac{F}{A}$$

Table 1 Manufacturer information, chemical formulations, and processing methods of the soft liners and primers evaluated

Brand	Manufacturer	Lot numbers	Components	Primer	Processing method
Ufi Gel SC	Voco, Cuxhaven, Germany	601407	Vinylpolysiloxane	A reactive polymer, a special silane, 2-butanone	Apply the primer to the surface and allow to dry for 1 minute. Soft liner is autopolymerizing
Sofreliner Tough	Tokuyama Dental Corporation, Tokyo, Japan	030	Poly(organosiloxane), amorphous silicone, A-silicone	Ethyl acetate 94% to 98%,PMMA with poly(organosiloxane), PMMA	Apply the primer, blow air to dry the primer, or leave it in well-ventilated area for 20 seconds. Soft liner is autopolymerizing
Vertex SoftSil 25	Vertex-Dental B.V., Zeist, The Netherlands	YR491D10	Vinylpolysiloxane	Solution of polyacrylate in dichloromethane	Apply the primer and allow to dry for 1 minute. Soft liner is autopolymerizing
Eversoft	Dentsply Austenal, York, PA		PMMA, dibuthyl phthalate, ethyl acetate, ethyl alcohol, methyl ethyl ketone (2-butanone)	N/A	Heat polymerized at 100°C for 15 minutes by compression molding or at 50°C to 74°C for 10 minutes at 1.4 bar using a jig
Palapress Vario	Heraus Kulzer GmbH, Hanau, Germany	012352	Powder: PMMA liquid: MMA, 1,4-BDMA	N/A	Pourable polymer system; 55°C at 2 kg/cm^2 pressure for 15 minutes
Stick	StickTech, Turku, Finland	2040915-R-0068	E-glass fibers preimpregnated with PMMA	N/A	Wet the Stick fibers with the monomer and cure with the denture

PMMA = poly(methyl methacrylate); MMA = methyl methacrylate; 1,4-BDMA = 1,4-butanediol dimethacrylate.

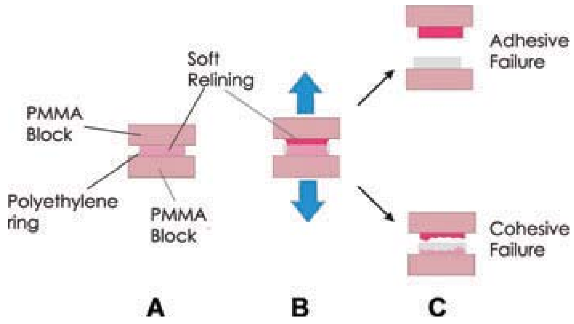

Figure 1 (A) Denture-base polymer substrates and soft liner; (B) tensile testing of the assembly; (C) classification of failure types as adhesive and cohesive-mixed.

where, σ = stress (MPa), F = maximum recorded force at failure (N), and A = original cross sectional area (mm^2);

$$\%\varepsilon = \frac{\Delta L}{L} \times 100$$

where, $\%\varepsilon$ = strain at fracture (percentage elongation), ΔL = extension, and L = original length (3 mm).

The failure types of the test groups were observed visually and classified as adhesive failures between the substrate and the liner or cohesive-mixed failures including a part of reline adhered to the bonding surface of the substrate (Fig 1C).

Data were analyzed with two-way analysis of variance (ANOVA), and when a significant interaction was found, one-way ANOVA and Tukey's test ($p = 0.05$) were used to determine significant differences between groups using statistical software (SPSS version 16.0; SPSS Inc, Chicago, IL). Failure types were statistically analyzed using chi-square test.

Results

Tensile bond strength results are given in Figure 2. The average tensile bond strength results ranged from 0.5 MPa (PMMA-FR, Eversoft to 3.2 MPa (PMMA-FR, Sofreliner Tough Two-way ANOVA revealed significant differences among the bond strength values of soft lining materials. The interaction between the factors (substrate and reline) was significant. One-way ANOVA revealed that FR layer caused a significant decrease ($p = 0.001$) in the bond strength of Ufi Gel SC to the denture-base resin Palapress Vario; whereas the other materials tested were not significantly affected by the FR. Sofreliner Tough gave the highest bond strength results for both substrate types ($p < 0.001$); whereas Eversoft gave the lowest ($p < 0.001$).

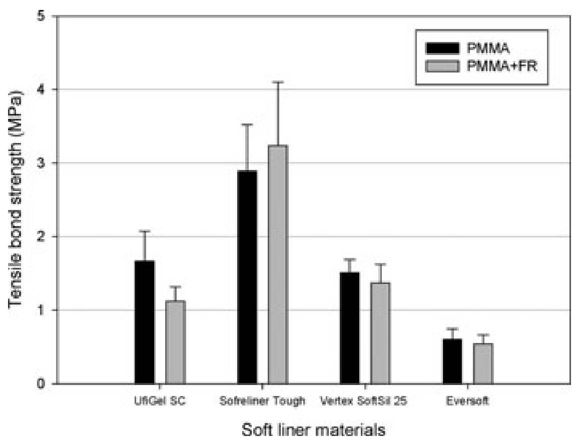

Figure 2 Tensile bond strength of the soft liner materials when bonded to PMMA or PMMA + FR substrates.

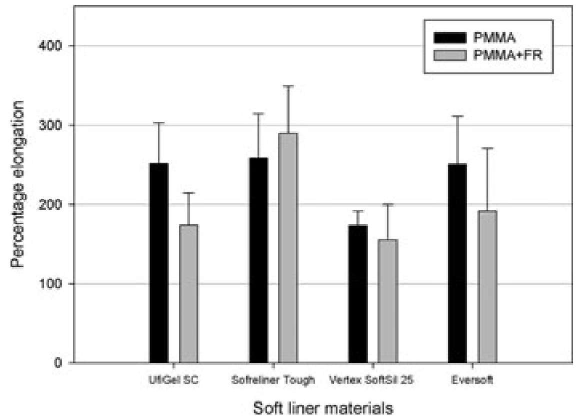

Figure 3 Percentage elongation (strain at fracture) of the soft liner materials when bonded to PMMA or PMMA + FR substrates.

Percentage elongation (% strain) results are given in Figure 3. Similar to the tensile bond strength results, only Ufi Gel SC showed a significantly different strain percentage result compared to the control group, decreasing from 251.5% to 174.1%.

Addition of FR to denture base resulted in changes in the failure modes of some of the groups (Fig 4). Sofreliner Tough failed mostly adhesively without FR application, but failure pattern changed to mixed in all the specimens after FR was used ($p < 0.001$, chi-square test). On the other hand, Eversoft showed cohesive-mixed failures when bonded to PMMA, but more than half the specimens failed adhesively when FR layer was used ($p = 0.014$, chi-square test).

Discussion

This study investigated the bond strength of three vinylpolysiloxane (VPS) and one plasticized acrylic soft liner to FR or unreinforced denture-base resin. The test method used when testing bond strength of soft liners influences the results.[5,18] Peel and shear test methods were reported to simulate the in vivo situation better than tensile test; however, the complexity of the failure mechanisms in these tests and higher probability of having cohesive failures make interpreting the results very difficult.[5,18–22] Tensile testing is useful in testing different processing methods and adhesives. It applies a simple tensile load to the specimen, and therefore, it is possible to record the percentage elongation and failure types;[18] however, tensile test may not be the only method to predict clinical performance because clinical failure mechanisms are usually

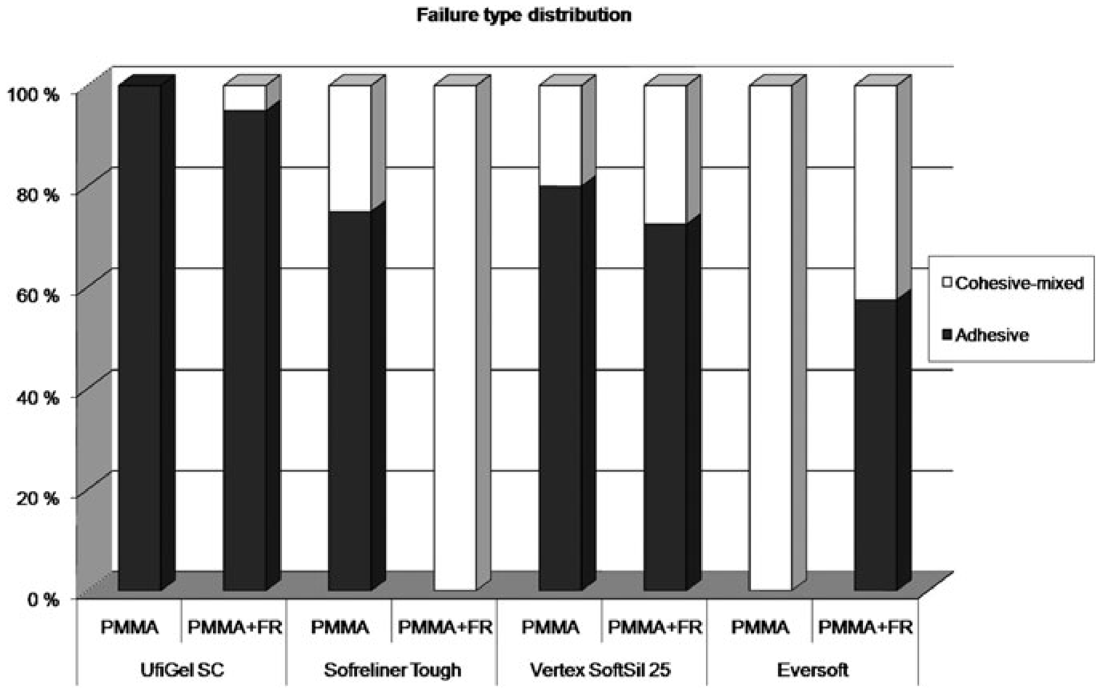

Figure 4 Failure type distributions of tested specimens.

more complex, involving stresses with various directions, fatigue, and the influence of water on the bonding interface and the materials.

The VPS materials used in this study were similar in chemical composition, but chemistry of the bonding agents varied. In previous reports, ethyl acetate was reported to be a relatively successful solvent for surface preparation and gave higher results than other solvents used for this purpose.[8,18] In the present study, the material with the highest bond strength, Sofreliner Tough, had an ethyl acetate-based bonding agent. When Sofreliner Tough was bonded to FR substrate, the bond strength increased slightly. The surface properties of the FR substrate may have contributed to the increased bond strength. The FR material used in this study was preimpregnated with noncrosslinked polymer that contains micrometer scale PMMA islands,[23] which might also be the reason for the slight increase of the bonding properties. As a result of the grinding procedure, the PMMA surface, together with the fibers, is exposed. This surface, which consists of a porous PMMA-impregnated glass-FR polymer, may have been better dissolved by ethyl acetate compared to a slightly crosslinked PMMA of the denture-base polymer surface, resulting in the slight increase in bond strength of the Sofreliner Tough.

When the surface of the FR group was ground, the glass fibers were also exposed, in addition to the preimpregnated PMMA matrix. This high percentage of glass at the bonding surface might also be a challenge for adequate bonding. The bonding strategy to inorganic glassy surface should be different compared to a PMMA surface.[23] Vertex SoftSil and Ufi Gel SC had similar bond strengths when they were bonded to the acrylic resin surface, but when bonded to the FR substrate, Ufi Gel SC had significantly lower bond strength. The difference may be due to the effect of the bonding agent of Ufi Gel SC. The cleaning effect, swelling effect, and drying effect[24,25] may not be as efficient on the FR surface compared to PMMA surface.

Ufi Gel SC showed a significant decrease in the percentage elongation values after FR (Fig 3). Resilient polymers elongate as they are subjected to tension. This elongation is influenced by the number of polymer chains parallel to the direction of force, filler-polymer bonding, and the degree of crosslinking.[26] Since the material used for control is the same as the material used against FR substrate, the decrease may be explained by the decreased bond strength. Since the bond strength of Ufi Gel SC decreased after fiber reinforcement, the soft liner was subjected to less tension, resulting in decreased elongation.

Failure types of soft liners are important in interpreting the results of bond strength tests. When the material fails cohesively, it may be concluded that the strength of the material is lower than the strength of the bond.[18] Previous studies had shown a change in the failure mode with restorative composites, when FR was used at the adhesive interface.[23] Similarly, in the current study, failure modes of Sofreliner Tough and EverSoft changed when FR was used. Sofreliner Tough revealed more cohesive failures after addition of FR. The change in failure mode was also accompanied by a slight increase in bond strength. This increase in bond strength apparently caused the liner to fail cohesively.

The failure modes may also give clues to the weak boundary layers causing early failure. EverSoft showed a tendency to fail adhesively after the addition of the FR layer (Fig 4). Eversoft is an acrylic-based plasticized soft liner. When the powder and liquid portions are mixed, the solvents swell and soften the

PMMA powder beads. This is a different procedure than the one used for polysiloxanes, and therefore, not comparable to the crosslinking that occurs in polysiloxanes. The bond to PMMA is possibly obtained by interpenetration and interpenetrating polymer network formation,[24] resulting in the cohesive failures obtained. On the other hand, the glass fibers exposed on the surface probably decreased bonding as EverSoft does not have a bonding agent that may improve bonding to glass fiber surface, resulting in an increase in the percentage of adhesive failures, as well as the slight decrease in the bond strength. The absence of a bonding agent for Eversoft liner may also have accounted for the low bond strength values observed.

The present study tested the initial tensile bond strengths of the soft liners bonded to water-immersed acrylic resin substrates. The stability of this bond in the oral environment under the effect of saliva and dynamic loading conditions however, needs to also be studied for a better understanding of the behavior of these materials during clinical service.

Conclusions

Within the limitations of the current study, glass FR did not have a decreasing effect on the bond strength, except for Ufi Gel SC. Clinically, an initial reduction in bond strength may result in earlier failure of the materials. Therefore, the choice of liner and bonding agent is important for an extended service life of FR dentures relined with soft liners.

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