Dental Materials Journal 26(2): 296−302, 2007

Effect of Thermocycling on Tensile Strength and Tear Resistance of Four Soft Denture Liners

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Received September 27, 2006 /Accepted December 15, 2006

This study evaluated the effect of thermocycling on the tensile strength and tear resistance of four long-term soft denture liners. One light-activated (Astron Light, AL), two chemically activated (GC Reline Soft, GC; Silagum Comfort, SC), and one heat-cured (Molloplast-B, MLP) soft liner materials were tested. Dumbbell and trouser-leg specimen geometries were used for tensile strength and tear resistance tests, respectively. A total of 120 specimens were prepared. Test specimens for each material (n=5) were subjected to thermal cycling for 1,000 and 3,000 cycles between 5℃ and 55℃ in a thermocycler. Before thermocycling, AL gave the lowest tensile strength, while SC exhibited the highest tear resistance value among the materials tested ($p<0.05$). Thermal cycling significantly affected the tensile strength of AL as well as the tear resistance values of AL, MLP, and GC materials. This *in vitro* study revealed that the tensile strength and tear resistance values of the soft liner materials tested varied according to their chemical compositions.

Keywords: Liner, Strength, Thermocycling

INTRODUCTION

Soft denture liners are generally used for edentulous patients who are unable to tolerate conventional dentures because of thin and relatively non-resilient mucosa or due to severe alveolar resorption[1,2]. Elasticity and resiliency of these materials enable them to act as a cushion for the denture-bearing mucosa through absorption and redistribution of forces transmitted to the stress-bearing areas of the edentulous ridges[3-6]. Soft denture liners are also a useful remedy when treating patients with ridge atrophy or resorption, bony undercuts, bruxism, congenital or acquired oral defects requiring obturation, xerostomia, and dentures opposing natural dentition[3,7,8]. Despite the favorable attributes and wide-ranging applications mentioned above, soft liners also have several problems associated with their use, such as poor tensile strength and tear resistance, debonding from denture base, poor color stability, and loss of softness[7,9,10].

Among soft liners with different chemical compositions, silicones—over and against plasticized acrylic soft liners—have been widely used because of good elastic properties[1,2] and clinical performance[11-13]. Silicones exhibit low water absorption and low solubility of components. Thus, silicone permanent materials remain more stable over a prolonged period of time, while acrylic permanent materials undergo a marked loss of cushioning effect over time[1,2]. However, recently, many types of silicones and soft acrylics are introduced to be used as chairside soft liners. Amongst which, new polyvinylsiloxane materials were reported to have a softness and elastic character similar to that of heat-cured silicones. Moreover, there is an added advantage of good handling properties, since they are supplied in a form which allows direct injection of the auto-mixed material onto the prepared denture fitting surface[14].

When considering the serviceability of soft liners in the oral environment, it is very important that they have adequate mechanical properties to withstand functional stresses applied to the material. Tensile strength provides information on the ultimate strength of a soft denture liner when subjected to tension, whereas elongation provides data on the ability of a material to deform prior to failure and thereby gives an indication of the flexibility of the material[15,16]. With rubber materials, tensile properties are a general guide to their quality[16]. As for tear resistance, it is a measure of a material's resistance to tearing forces[17]. In particular, it affects the clinical performance of soft denture materials when subjected to conditions which could initiate tearing, such as the denture cleaning procedures[16].

Soft denture liners are expected to function in the aqueous oral environment for long periods of time as well as under rapidly changing temperatures. However, it must be noted that with cyclic temperatures, the thermal behaviors of the structural components within a material can influence the latter's mechanical and physical properties[15,18]. In this connection, the thermocycling process can give useful data on the longevity of soft denture liners, with respect to mechanical properties under conditions that simulate clinical usage.

This study evaluated the cumulative effects of thermally induced stresses (thermocycling) on the tensile strength, elongation at break, and tear resistance of four commercially available soft denture liners at different cycling intervals. The null hypothesis for this study was that a heat-cured polysiloxane-based soft liner, Molloplast-B, would give the highest tensile strength and tear resistance values after thermocycling.

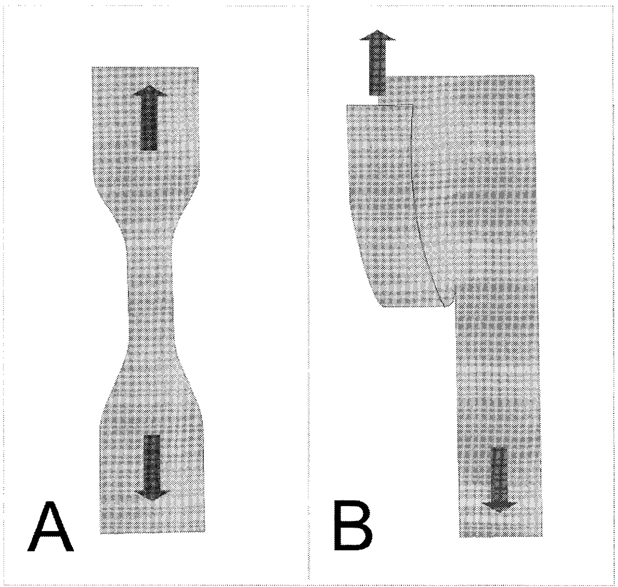

Fig. 1 Illustration showing (A) tensile strength test specimen, and (B) tear resistance test specimen.

MATERIALS AND METHODS

Specimen preparation

In this laboratory study, one light-activated, one heat-cured, and two chemically activated soft denture liners were tested to determine the effect of thermocycling on tensile strength and tear resistance. The names, components, manufacturers and polymerization types of these soft denture liners are presented in Table 1. For tensile strength tests, a gypsum mold was made by using a standard polytetrafluoroethylene (PTFE) dumbbell pattern in accordance with ASTM 0638 M (Standard test method for rubber property—tensile strength) (Fig. 1A)[19]. To avoid uncontrolled stresses during the test, mid-section of PTFE pattern was formed into a cylindrical shape with a diameter of 2.5 mm along the thin section. As for tear specimens, they were prepared with a 50 mm long, 10 mm wide, and 1 mm thick aluminum pattern and partly divided along the center of the long axis to form what is colloquially described as a "trouser leg specimen (Fig. 1B)[20].

Soft denture liners were packed into molds and cured according to the manufacturers' instructions. Astron Light (AL) was polymerized in a Triad curing unit (Triad 2000, Dentsply, York, PA, USA) for 10 minutes. Molloplast-B (MLP) was polymerized in boiling water for two hours. The polymerization of two chemically activated materials, GC Reline Soft (GC) and Silagum-Automix Comfort (SC), were completed with a conditioner (Kottermann, Labortechnik, Hanigsen, Germany) at 40−50℃ for 10 minutes to simulate a chairside reline technique.

Table 1 Materials used in this study

Brand name (Code)	Components	Manufacturer	Curing method
Astron Light (AL)	Butyl methacrylate, Bis-EMA, PEMA	Astron Dental, Lake Zurich, IL	Light activated
Molloplast-B	Hydroxyl terminated polydimethylsiloxane, fumed silica fillers, methyl triacetoxysilane, dibutyl tin dilaurate, PMMA, and γ-methacryloyloxy-propyltrimethoxysilane as primer**	Detax GmbH, Ettlingen, Germany	Heat-cured
GC Reline Soft (GC)	Silicone dioxide, vinyl dimethyl polysiloxane, hydrogen polysiloxane*	GC Co., Tokyo, Japan	Autopolymerized
Silagum Comfort (SC)	Vinylsilicone, hydrogen silicone, aerosil, additives	DMG, Hamburg, Germany	Autopolymerized

Bis-EMA Bisphenol-A-diethyl methacrylate
PEMA Poly(ethyl methacrylate)
PMMA Poly(methyl methacrylate)
* Composition according to the material safety data sheet supplied by the manufacturer
** Braden *et al.*[26]

Thermocycling

A total of 120 specimens were prepared for both tensile strength and tear resistance tests (60 specimens for each test). Specimens were randomly assigned to three test groups (n=5), and they were either thermocycled for 1,000 or 3,000 cycles between (5±1)℃ and (55±1)℃ with a 60-second dwell time in a thermocycler, or stored for 24 hours in distilled water at (37±1)℃.

Mechanical tests

Mechanical tests were performed on a universal testing machine (Lloyd LRX, Lloyd Instruments Ltd., Fareham, Hampshire, UK) at a crosshead speed of 50 mm/min. Data were collected using a personal computer with a Nexygen software (Nexygen, Lloyd Instruments Ltd., Fareham, UK). Tensile strength, percent elongation (strain at fracture), and tear strength were then calculated automatically by the software using Equations (1)−(3) below[16,21]:

$$T = \frac{F}{A} \qquad (1)$$

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

$$\%ef = \frac{\Delta L}{L} \times 100 \qquad (2)$$

where *%ef*=percent elongation (strain at fracture), ΔL=extension, and L=original length;

$$Ts = \frac{F}{t} \qquad (3)$$

where Ts=tear resistance (N/mm), F=maximum force to tear specimen (N), and t=thickness of specimen (mm).

Statistical analysis

Data obtained from both tests were analyzed with one-way analysis of variance, ANOVA, using a statistical software (SPSS version 11.0 software, SPSS Inc., Chicago, IL) on a personal computer. The means and standard deviations were recorded for each group, and Tukey's HSD test was used to determine significant differences between groups.

RESULTS

Tensile strength

Table 2 shows the mean and standard deviation values of the tensile strength of specimens. There were statistically significant differences among the tensile strengths of control groups. AL had a lower tensile strength compared to the other materials ($p<0.05$), whereas GC had the highest tensile strength of all the materials tested ($p<0.05$). As for differences between MLP and SC, as well as between GC and SC, they were not statistically significant ($p>0.05$). However, the difference between MLP and GC was found to be significant ($p<0.05$). After 3,000 thermal cycles, the tensile strength of AL increased significantly ($p<0.05$). However, 1,000 and 3,000 cycles of

Table 2 Mean tensile strength values

	Control (MPa)		After 1,000 cycles (MPa)		After 3,000 cycles (MPa)	
	Mean	SD	Mean	SD	Mean	SD
AL	$0.60^{a,x}$	0.18	$0.38^{a,x}$	0.23	$0.96^{a,y}$	0.46
MLP	$3.03^{b,x}$	0.75	$2.22^{b,x}$	0.58	$2.51^{b,x}$	0.65
GC	$4.42^{c,x}$	0.83	$5.12^{c,x}$	0.66	$4.81^{c,x}$	0.93
SC	$3.72^{b,c,x}$	0.31	$3.87^{c,x}$	1.03	$4.16^{c,x}$	0.50

Groups with same superscript letters, a-d vertically and x-z horizontally, are not significantly different ($p>0.05$)

Table 3 Percent elongation (strain at fracture) of soft liners as a function of thermocycling

	Control (MPa)		After 1,000 cycles (%)		After 3,000 cycles (%)	
	Mean	SD	Mean	SD	Mean	SD
AL	$205.56^{a,x}$	28.49	$171.26^{a,x,y}$	41.28	$124.25^{a,y}$	30.29
MLP	$195.63^{a,x}$	82.87	$129.92^{a,x}$	62.44	$146.57^{a,b,x}$	39.35
GC	$210.22^{a,x}$	29.65	$193.51^{a,b,x}$	13.13	$199.78^{b,x}$	48.06
SC	$268.82^{a,x}$	25.44	$250.78^{b,x}$	16.06	$293.60^{c,x}$	29.42

Groups with same superscript letters, a-d vertically and x-z horizontally, are not significantly different ($p>0.05$)

thermocycling did not affect the tensile strengths of MLP, SC, and GC ($p>0.05$).

Percent elongation

Table 3 shows the mean and standard deviation values pertaining to percent elongation of tensile strength specimens. There were no statistically significant differences among the control groups, and the polysiloxane materials also did not show significant changes after 1,000 and 3,000 thermal cycles ($p>0.05$). However, AL material showed a significant decrease after 3,000 thermal cycles ($p<0.05$).

Tear resistance

Table 4 shows the tear resistance results. Among the control groups, no significant differences were found among AL, MLP, and GC ($p>0.05$), whereas SC had the highest tear resistance and which was significantly different from the other materials ($p<0.05$). After 1,000 and 3,000 thermal cycles, AL exhibited a significant increase in tear resistance ($p<0.05$). With MLP, its tear resistance decreased after 1,000 thermal cycles, but this did not cause a significant difference compared to the control group ($p>0.05$). However, after 3,000 thermal cycles, the increase of tear resistance of MLP was significant when compared to the control and 1,000-cycle groups ($p<0.05$). With GC, its tear resistance significantly decreased after 1,000 and 3,000 cycles of thermocycling ($p<0.05$). With SC, thermocycling did not have any significant effect on its tear resistance ($p>0.05$).

DISCUSSION

Soft denture liners are expected to function in the oral environment for long periods of time. As such, various accelerated aging methods have been applied to these materials to simulate the oral conditions[7,15,18,22-25]. By means of thermocycling, cumulative effects of fatigue arising from sudden temperature changes can be determined. In the current study, soft denture liners were subjected to fatigue stress by virtue of temperature differences between water baths of a thermocycler. Temperature variation between 5℃ and 55℃ was chosen as these temperatures depict the temperature range of foods ingested during meals and which do not damage oral tissues[24]. As to the use of 1,000 and 3,000 thermal cycles, the objective was to evaluate the cumulative effect of fatigue within soft denture liner materials rather than to represent a certain wearing time for soft denture liners.

The heat-cured silicone material tested in this study was widely accepted and recognized to be the most successful silicone rubber soft denture liner available. It was reported as being superior to both autopolymerized silicones and plasticized acrylic materials in terms of longevity[11-13,16]. On these grounds, the null hypothesis of this study was that heat-cured silicone material would give the highest tensile strength and tear resistance values. The underlying assumption was that this material was composed of a strong network structure. Thus, it might be harder to break the bonds of this material, partly because of the polymerization conditions used. As for the other two chemically activated silicone soft denture materials, they had a similar chemical composition with the heat-cured silicone. Then, owing to a polysiloxane structure in their composition, they were readily curable by crosslinking at a low temperature and pressure, as compared to compression molding technique.

Among the many desired mechanical properties of a soft denture liner, high tensile strength and tear resistance are of particular practical importance to the final product[21]. Tensile strength indicates the maximum tensile stress that can be applied uniformly over the cross-section of a test piece in the course of stretching the test piece to failure. Tear resistance, on the other hand, measures the resistance to growth of a nick or cut when tension is applied to a cut sample. The apparent differences in the nature of these tests might make the results obtained very different. For example, a material can have a very high crosslink density and survive tension; but, it fails prematurely in tear tests as the reinforcing properties of the silica filler and polysiloxane chains in the crosslink fail to stem the propagation of a cut. With soft denture liners, tear resistance is probably the most important mechanical

Table 4 Mean tear resistance values

	Control (MPa)		After 1,000 cycles (MPa)		After 3,000 cycles (MPa)	
	Mean	SD	Mean	SD	Mean	SD
AL	$0.74^{a,x}$	0.17	$1.86^{a,y}$	0.39	$4.12^{b,z}$	1.00
MLP	$1.14^{a,x}$	0.25	$1.06^{a,x}$	0.31	$1.52^{a,y}$	0.12
GC	$2.08^{a,x}$	0.22	$1.58^{a,y}$	0.27	$1.54^{a,y}$	0.27
SC	$10.11^{b,x}$	2.22	$13.07^{b,x}$	3.38	$11.77^{c,x}$	1.49

Groups with same superscript letters, a–d vertically and x–z horizontally, are not significantly different ($p>0.05$)

property as they are prone to tearing when subjected to chemical or mechanical cleaning.

As opposed to soft acrylics which owe their compliance to the presence of a plasticizer, most polyvinylsiloxane soft liners contain silica fillers in varying quantities. It was suggested that the strength of filler-polymer bonding would affect the tear and tensile properties of soft denture liners— moreover, the stronger the filler-polymer bonding, the better it would be for these properties[16,21]. In this study, only one acrylic-based material was tested, namely GC. It had the highest tensile strength at 4.42 MPa before thermocycling, whereas AL material had the weakest one at 0.60 MPa. This was probably due to their different chemical structures. Although the exact formulation of GC was not publicly disclosed, it was well known that an external plasticizer was added to the methacrylate-based system to reduce the glass transition temperature. The plasticizer then acted as a lubricant between the polymer chains, enabling them to move past or slip by each other and thus deformed more easily[26]. Additionally, it has been demonstrated that free, unreacted monomers remained within the polymerized resin after curing, thereby resulting in inferior mechanical properties[27]. Therefore, the poorest tensile strength could be attributed to the presence of free, unpolymerized monomers remaining in the AL material after light curing. As for the heat-cured MLP material, its mean tensile strength of 3.03 MPa was weaker than both chemically activated materials, GC and SC. This could be due to the different components in their formulations (Table 1), as well as due to filler-polymer matrix interaction.

The tensile strength of MLP material was found to be higher than the 2.12 MPa reported by Waters and Jagger[16], probably due to the latter's application of a higher deformation rate. According to Aziz *et al.*[21], the higher the rate of deformation, the less time the molecules have to redistribute the stress and this leads to premature tearing of the specimen, thus giving a low value.

As for the effect of thermocycling, there were no statistically significant differences in tensile strength between the control specimens and those after 1,000 and 3,000 cycles of thermocycling for MLP, GC, and SC. However, 3,000 cycles of thermocycling affected the tensile strength of AL material by increasing it to 0.96 MPa from 0.60 MPa. It could be that during thermocycling, the AL material hardened due to the loss of plasticizer[18,22]. Indeed, the significant decrease in percent elongation after 3,000 thermal cycles (Table 3) supported this suggestion.

As for the tear resistance of soft lining materials, this property is influenced by many factors, such as degree of crosslinking, molecular weight of polysiloxane chains, and silica filler concentration[21]. In the same vein, it was reported that surface-modified silica fillers increased the tear resistance of soft denture lining materials[16,21]. In this study, SC had the highest tear resistance and was significantly different from the other materials tested ($p<0.05$). Many reasons were thought to contribute to this tear resistance value: high degree of orientational order of polymer chains due to high degree of crosslinking, increased strength of filler-matrix interaction, and high filler content. Indeed, while 1,000 and 3,000 cycles of thermocycling affected the tear resistance of AL, MLP, and GC materials, SC material maintained stability in this respect.

The tear resistance of AL was not found to be significantly different from those of MLP and GC materials ($p>0.05$), although it was determined as the weakest material among the materials tested. This finding was in sharp contrast to a previous report[18], whereby acrylic-based soft liners had higher tear resistance than silicone-based ones. After thermocycling, the significant increase in tear resistance of AL material could be due to the loss of plasticizer during thermocycling, thereby leading to hardening, as suggested by Leon *et al.*[25].

Similar to AL, the tear resistance of MLP material increased from 1.14 N/mm to 1.52 N/mm after 3,000 cycles of thermocycling. According to McCabe[14], this material had a significant weight loss after being soaked in water for 90 days. This might well reflect the loss of condensation reaction by-products or catalyst by-products. Likewise, this might well explain why MLP exhibited an increase in tear resistance after thermocycling. On the other hand, Dootz *et al.*[18] reported that the tear resistance of MLP increased from 5.4 N/mm to 7.9 N/mm after an accelerated aging process in a Weather-Ometer device. They concluded that this increase was probably a result of continuing polymerization. In our present study, the tear resistance value of MLP was found to be slightly lower than the previous findings[18]. Differences in tear resistance values might be attributed to differences in test conditions in terms of test specimen geometry, deformation rate, and the aging procedure used.

Although SC was the material with the greatest tear strength, its tensile strength and percent elongation values were comparable with those of GC soft liner material. While thermocycling had no deleterious effect on the tear strength of SC, it had a significant effect on GC such that its tear resistance value decreased significantly ($p<0.05$). This could be due to different components used in their formulations. Although these two materials were addition type of polysiloxane-based soft liners, GC was likely to contain a lower amount of fillers or consist of lower-molecular-weight polymers. Further, the surface of the silica fillers of GC might be unmodified, thereby causing GC to absorb a larger amount of water than SC after thermocycling. This was because the presence of $-OH$ groups on the non-treated surface of silica fillers helped to absorb water into the polymer matrix[21]. The absorbed water molecules then acted as plasticizers and facilitated the movement of polymer chains. Theoretically, this plasticizing effect would decrease the strength of the polymer[28]. Nonetheless, this proffered suggestion awaits further clarification in a future work.

The null hypothesis in this study was rejected, since the tensile strength and tear resistance of chemically activated GC and SC materials were greater than those of heat-cured MLP silicone liner material. From a clinical standpoint, these new materials could be alternatives to Molloplast-B because of their better handling properties. Nonetheless, to ensure long-term clinical success, the other mechanical and physical properties of GC and SC—apart from tensile strength and tear resistance—should also be investigated.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following conclusions were made:

1. Before thermocycling, Astron Light material exhibited a significantly lower mean tensile strength than the other soft denture materials tested ($p<0.05$).
2. With 3,000 cycles of thermocycling, the tensile strength of Astron Light material was increased. On the other hand, 1,000 and 3,000 cycles of thermal cycling had no deleterious effect on the tensile strengths of Molloplast-B, GC Reline Soft, and Silagum Comfort soft denture liners.
3. Before thermocycling, Silagum Comfort material gave the highest tear resistance value—which was significantly different from the other materials tested ($p<0.05$).
4. While 1,000 and 3,000 cycles of thermal cycling did not affect the tear resistance of Silagum Comfort, thermocycling significantly affected those of Astron Light, Molloplast-B, and GC Reline Soft liner materials.

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