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The Effect of Aging by Thermal Cycling and Mechanical Brushing on Resilient Denture Liner Hardness and Roughness

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Abstract

Purpose: The purpose of this study was to investigate the effects of aging on resilient denture liners. The aging effects were produced by using thermal cycling and mechanical brushing and were quantified as changes to surface hardness and roughness of resilient denture liners.
Material and Methods: A plasticized acrylic resin (Dentuflex) and two silicone-based (Molloplast-B, Sofreliner MS) resilient denture liners were examined. Pre- and post-test roughness and hardness measurements were recorded using a Surfcorder SE 1700 and Shore A durometer Teclock GS-709, respectively. Sixty specimens were manufactured; half were subjected to 3000 cycles in the thermal cycler (5 and 55°C). The remaining specimens received 30,000 strokes applied by a mechanical brushing machine followed by 3000 thermal cycles. Representative specimens from each group were observed under scanning electron microscope (SEM). Data were examined by multiple ANOVA, split-plot analysis, and Tukey test ($\alpha = 0.05$).
Results: Shore A hardness values for Dentuflex, Molloplast-B, and Sofreliner MS soft liners were different from each other ($p < 0.05$) before (79 ± 2.9; 40 ± 1.4; 33 ± 0.7) and after (80 ± 3.1; 40 ± 1; 34 ± 0.9) thermocycling. The surface roughness (in μm) of the same soft liner materials was significantly different ($p < 0.05$) at the start (2.2 ± 0.4; 1.6 ± 0.6; 0.2 ± 0.1) but it was not different ($p > 0.05$) after tooth brushing (1.7 ± 0.3; 1.7 ± 0.4; 1.9 ± 0.8) or thermocycling (1.6 ± 0.5; 1.6 ± 0.6; 1.5 ± 0.5)
Conclusion: Thermal cycling promoted increased hardness for Sofreliner MS and Dentuflex. Mechanical brushing promoted wear abrasion in Sofreliner MS and Dentuflex materials. Molloplast-B experienced no deleterious effects from either of the tests.

Soft lining materials are used to replace the intaglio surface of a conventional hard denture when patients cannot tolerate the hard denture base.[1] Without a soft liner, the hardness of a poly(methyl methacrylate) (PMMA) surface may lead to chronic irritation, possibly due to pressure on the mental foramen, sharp bony specula, bony undercuts, thin atrophic mucosa, irregular bone resorption, bruxism, and/or incorrect occlusal relationship.[2-4] Soft liners made of two basic groups of materials, plasticized acrylics and silicone elastomers, are commercially available.[1,3-5] Plasticized acrylic materials generally consist of powder and liquid components. The compositions of the components are generally thought to comprise acrylic polymers and copolymers along with a liquid containing an acrylic monomer and plasticizers (ethyl alcohol and/or ethyl acetate), responsible for maintaining material softness.[3,4,6,7] Silicone materials are basically composed of dimethylsiloxane polymers, similar in composition to the silicone impression materials.[5] It has been suggested that the initial softness of plasticized acrylics is due to the large quantity of plasticizer in the liquid.[3,4,7,8] No plasticizer is necessary to produce a softening aspect in silicone materials, because poly-dimethylsiloxane is a viscous liquid added to an arrangement that can be cross-linked to form a rubber with good elastic properties.[3,4] During clinical use, the denture lining materials are immersed in saliva and, when not in use, may be soaked in water or cleansing agents.[11] When immersed in such solutions, plasticizers and other components may leach out over extended periods, while water or saliva is absorbed. The loss of plasticizer may cause decreased percent elongation and increased hardness values.[2,4] Material arrangement, chemistry, and polymerization mode can also promote hardening with time.[5,9,10]

Denture lining material surface properties are of clinical importance, because they may affect plaque accumulation.[11-13] Due to the abrasive effect of mechanical brushing,[14,15] toothpaste particle size, bristle stiffness, and type of abrasive may influence surface roughness,[8,16] creating the potential for bacterial growth, plaque accumulation, and calculus formation.[4,11] Therefore, good homecare and periodic replacement of resilient denture liners are required.[3,4]

Although there are several reports in the literature regarding denture lining materials, few evaluated their properties after simulating aging using thermal cycling.[3,4] Due to the limitations of these materials and lack of studies about the subject, the purpose of this in vitro study was to investigate the effect of aging, created by thermal cycling and mechanical brushing, on the hardness and roughness of three commercially available resilient denture liners.

Materials and methods

Three soft denture liners, one high temperature vulcanizing (HTV) silicone rubber (Molloplast-B®), one room temperature vulcanizing (RTV) silicone rubber (Sofreliner MS®), and 1 RTV plasticized acrylic (Dentuflex®) were selected for this study (Table 1). Rectangular specimens (25×13 mm^2) were prepared by investing 3-mm-thick dies in a denture flask. The dies were made of silicone rubber (Zetalabor, Zhermack, Rovigo, Italy) and invested with a glass plate and die stone (Fuji-Rock, GC America, Chicago, IL). Twenty specimens were made of each material by processing the resilient denture liners against the glass plate. After polymerization, specimens were removed from the flask, and the flash was removed with a sharp knife surgical blade (model 11, Havel's, Inc., Cincinnati, OH). Afterwards, the specimens were stored in a thermostatically controlled distilled water bath at 37 ± 1°C for 24 hours. Next, all specimens were dried with absorbent paper and submitted for initial hardness and roughness readings. The control group was represented by the initial hardness and roughness readings of all 60 specimens before the tests started. Half the specimens were subjected to thermal cycling and the other half to mechanical brushing followed by thermal cycling. For the purpose of observation by scanning electron microscope (SEM), a further sample of each material was prepared.

Hardness was determined by means of a Shore A durometer (model GS-709, Teclock, Osaka, Japan) vertically attached to a support (model GS-2002, Woltest, São Paulo, Brazil). The instrument consists of a blunt-pointed indenter attached to a scale by a lever arrangement with a recording scale from 0 to 100 Shore A units. The more the indenter penetrates the specimens, the lower the hardness values. Five indentations were recorded per specimen under a load of 1 kg and 1 second time reading before and after testing. For standardization, the specimens were placed on a glass slab during testing.

Roughness was determined by roughness average (Ra) using a roughness machine (Surfcorder SE 1700, Kosaka Laboratory, Tokyo, Japan) with a diamond stylus traversing a length of 2.4 mm and a cut off length of 0.8 mm at a speed of 0.5 mm/sec. Three readings were recorded for each specimen before and after testing.

The thermal cycled specimen group was immersed in distilled water and treated in a thermal cycler (MSCT-3 plus, Marcelo Nucci-ME, São Carlos, Brazil) for 3000 cycles at temperatures ranging from 5 to 55°C with a 60-second dwell time per temperature.[3,4] The number of cycles was used to simulate total prosthesis use for approximately 2 years. A prosthesis-wearing patient, who eats three times a day for 2 years, would have eaten 2190 meals at the end of that time.[4] This calculation is based solely on a single thermal cycle per meal. The temperature variations were chosen on the basis of the similarity of temperatures of foods ingested during meals and were not damaging to oral tissues.

For the mechanical brushing test, a tooth brushing machine (MSEt, Marcelo Nucci-ME), with an engine that imparted a reciprocating motion to ten toothbrush heads, was used. Johnson Reach '30 extra-soft brushes (Johnson & Johnson, São Paulo, Brazil) were used at an applied load per brush head of 200 g at a rate of 150 cycles per minute.[15] An abrasive solution, prepared by mixing 6 ml distilled water with 6 g of toothpaste (Sorriso, Colgate-Palmolive, São Paulo, Brazil), was released at 1-minute intervals during the test. The testing temperature was 25°C. The specimens were subjected to 30,000 strokes with linear brushing movements followed by 3000 thermal cycles. The brushing period was selected because a specific area on a denture receives 15 strokes at each brushing, and dentures are brushed three times a day. Therefore, 30,000 strokes would be equivalent to approximately 2 years of cleaning.[14] Hardness and roughness data were recorded between tests and on completion. The samples prepared for examination by SEM were mounted on aluminum stubs, sputter coated with gold (Denton Vacuum Desk II, Moorestown, NJ), and subjected to SEM (JSM-5600 LV, JEOL, Tokyo, Japan) at a 0° angle; magnifications were standardized at $\times 250$. The purpose of the SEM was to illustrate the surface alterations that occurred in the samples before and after the tests.

The data were subjected to statistical analyses: (1) descriptive statistics, (2) analysis of variance (ANOVA), split-plot analysis and (3) Tukey comparison test. All data analyses were performed at an $\alpha = 0.05$ level of significance.

Table 1 Materials used

Soft denture liner material	Type and curing conditions	Manufacturer	Lot no.
Dentuflex®	Autopolymerized Plasticized acrylic	Dental Medrano, Buenos Aires, Argentina	12403
Sofreliner MS®	Autopolymerized silicone rubber	Tokuyama Corp., Tokyo, Japan	U45233
Molloplast-B®	Heat-cured silicone rubber (100°C, 2 hours, slow cool immersed)	Dentax GmbH & Co., Ettlingen, Germany	11262

Table 2 Results of Shore A hardness for thermal cycling test

Material	Control	Thermocycled
Dentuflex	79 ± 2.9 A,a	80 ± 3.1 A,b
Sofreliner MS	33 ± 0.7 B,a	34 ± 0.9 B,b
Molloplast-B	40 ± 1.4 C,a	40 ± 1 C,a

Mean values followed by the same capital letters in columns do not differ with statistical significance, $p > 0.05$.
Mean values followed by the same lower case letter in rows do not differ with statistical significance, $p > 0.05$ (n = 10).

Results

Table 2 presents mean hardness values for all materials before and after thermal cycling. Statistical analysis indicated that thermal cycling had no effect on Molloplast-B specimens ($p > 0.05$); however, thermal cycling caused differences in Dentuflex and Sofreliner MS specimens ($p < 0.05$). Table 3 presents Ra values (μm) for all materials subjected to mechanical brushing followed by thermal cycling. Lower values were observed for Dentuflex after mechanical brushing; however, mechanical brushing caused an increase in value for Sofreliner MS ($p < 0.05$). Mean roughness values decreased for all materials after thermal cycling, which showed no effect on roughness ($p > 0.05$) (Table 3). Figure 1 shows all materials before and after treatment.

Discussion

The specimens were stored in a thermostatically-controlled, distilled water bath at 37 ± 1°C during testing with the aim of simulating the intraoral environment;[17] however, as the distilled water did not have the same composition as saliva, the storage of the specimens might have interfered in the results of study. The abrasion process observed for both materials is due to the toothpaste particle size, particle distribution, and abrasive type (calcium carbonate).[16] Thus, the decreased roughness values observed for Dentuflex can likely be explained by the high hardness values (Table 2) that promoted polishing and surface particle loss (Fig 1A).[8,14] The increased roughness values observed for Sofreliner MS occurred because the surface wears by abrasion, creating grooves in the material (Fig 1B), resulting in a surface with a potential for bacterial growth, plaque formation, and calculus accumulation.[3,4,11–13] With regard to hardness, increased values promoted by thermal cycling are probably due to the different compositions of each denture liner.[5] Dentuflex is a plasticized acrylic resin material, consisting of powder (polymers and co-polymers) and liquid (acrylic monomer and a plasticizer). The plasticizer lowers the glass transition temperature of the polymer to a satisfactory value, making the material soft in the mouth.[5] The amount of plasticizer in the liquid can influence the hardness values; therefore the less plasticizer used, the harder the material will become. Similarly, loss of plasticizer increases the hardening process.[4,8]

Thermal cycling promoted leaching of plasticizer in Dentuflex. Plasticizer loss is due to a threefold sequence of events occurring at the same time: (1) ethanol loss, (2) water sorption, and (3) plasticizer loss. Plasticizer loss promotes hardening of the material and an increase in the mean Shore A values (Table 2). Sofreliner MS is a silicone-based material containing polymethylmethacrylate polymers. Thermal cycling caused the material to harden and increased the mean Shore A value slightly over time (Table 2).

Although the materials tested in this study are classified as a chemical-curing acrylic resin plasticizer (Dentuflex), and two silicone-based, chemical-curing (Sofreliner MS) and heat-curing (Molloplast-B) materials, the results may have been influenced by material composition and polymerization mode.[10] One can postulate that Molloplast-B exhibited higher hardness values because of a more complete polymerization reaction as a result of the heat-cured process. The dymethylsiloxane polymer structure of Molloplast-B has a large quantity of cross linkage; consequently, this material presents good elastic and resilient properties and great stability over time,[4,10] thus maintaining hardness values even after the test (Table 2). After mechanical brushing followed by thermal cycling, all materials exhibited decreased roughness values, but without statistically significant differences (Table 3).

Laboratory studies simulate an oral environment; however, simulations are not without limitations. One of the limitations of the present study is that in the intraoral medium, the aging that occurs as a result of thermal cycling and mechanical brushing tests tends to take place simultaneously, whereas in this study it did not. Consequently, the material(s) with the least change in softness and surface roughness with age would be the most clinically applicable. Even so, in this study the hardening process occurred after thermal cycling for Dentuflex and Sofreliner MS; further clinical studies are necessary. Under the tested conditions, the silicone-based Molloplast-B was the only material to retain its physical properties, even after having grooves and particle loss (Fig 1C).

Table 3 Results of roughness values in Ra (μm) for mechanical brushing test

Material	Control	Brushed	Thermocycled
Dentuflex	2.2 ± 0.4 A,a	1.7 ± 0.3 A;a,b	1.6 ± 0.5 A,b
Sofreliner MS	0.2 ± 0.1 B,a	1.9 ± 0.8 A,b	1.5 ± 0.5 A,b
Molloplast-B	1.6 ± 0.6 A,a	1.7 ± 0.4 A,a	1.6 ± 0.6 A,a

Mean values followed by the same capital letters in columns do not differ with statistical significance, $p > 0.05$.
Mean values followed by the same lower case letter in rows do not differ with statistical significance, $p > 0.05$ (n = 10).

Conclusion

Within the limitations of the experiments, the following could be concluded:

1. Mechanical brushing caused a statistically slight increase in the surface roughness for Sofreliner MS (from 0.2 ± 0.1 to 1.9 ± 0.8 μm, $p < 0.05$) and a slight decrease in surface roughness for Dentuflex after thermal cycling (from 2.2 ± 0.4 to 1.6 ± 0.5 μm, $p < 0.05$).

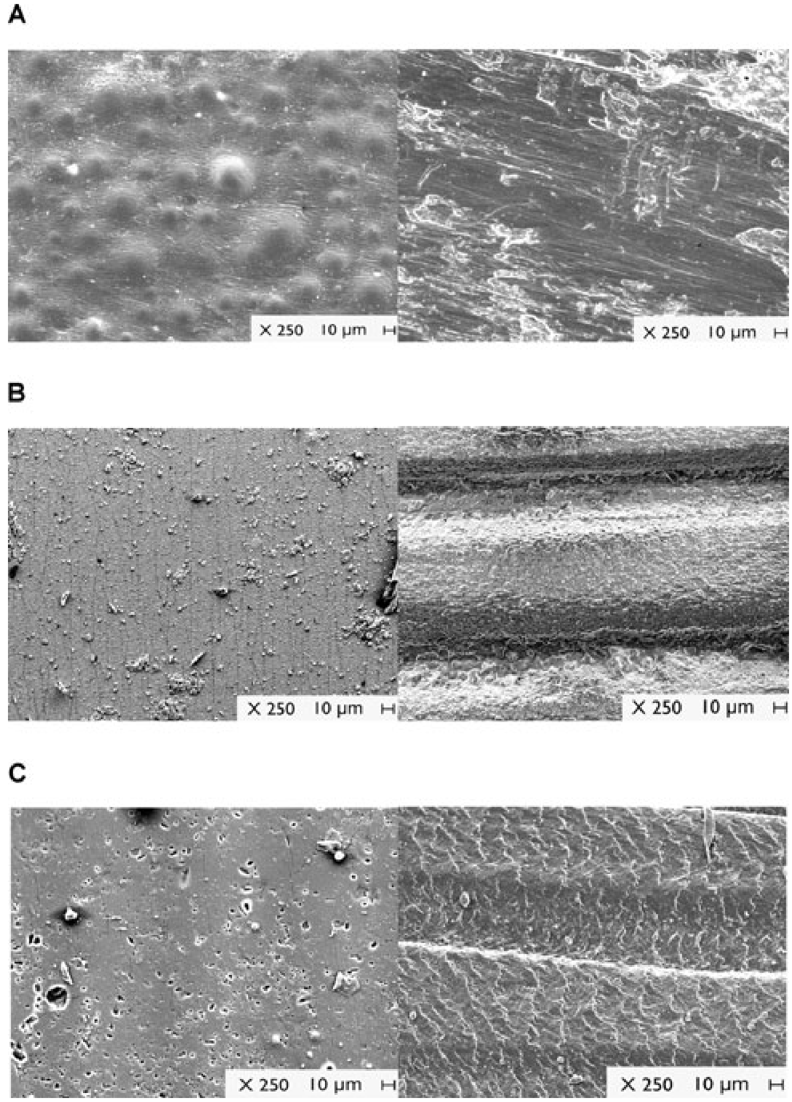

Figure 1 (A) SEM photograph: Dentuflex before (l) and after (r) test. (B) SEM photograph: Sofreliner MS before (l) and after (r) test. (C) SEM photograph: Molloplast-B before (l) and after (r) test.

2. There was no significant difference in surface roughness for any of the three materials before and after thermal cycling after brushing ($p > 0.05$), or among the three materials ($p > 0.05$).
3. After testing, Molloplast-B did not change in hardness or roughness ($p > 0.05$).

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References

1. Hayakawa I, Keh ES, Morizawa M, et al: A new polyisoprene-based light-curing denture soft lining material. J Dent 2003;31:269–274
2. Qudah S, Hugget R, Harrison A: The effect of thermocycling on the hardness of soft lining materials. Quintessence Int 1991;22:575–580
3. Pinto JRR, Mesquita MF, Pessanha GE, et al: Effect of thermocycling on bond strength and elasticity or 4 long-term soft denture liners. J Prosthet Dent 2002;88:516–521
4. Pinto JRR, Mesquita MF, Nóbilo MAA, et al: Evaluation of varying amounts of thermal cycling on bond strength and permanent deformation of two resilient denture liners. J Prosthet Dent 2004;92:288–293
5. McCabe JF: Soft lining materials: composition and structure. J Oral Rehabil 1976;3:273–278
6. McCarthy JA, Moser JB: Mechanical properties of tissue conditioners. Part I: theoretical considerations, behavioral characteristics, and tensile properties. J Prosthet Dent 1978;40:89–97
7. Brow D: Resilient soft liners and tissue conditioners. Br Dent J 1988;164:357–360
8. Botega DM, Filho JLC, Mesquita MF: Influence of tooth brushing in surface roughness of soft denture liner: an *in vitro* study. Revista de Pós-Graduação 2004;11:125–129

9. Hekimoglu C, Anil N: The effect of accelerated aging on the mechanical properties of soft denture lining material. J Oral Rehabil 1999;26:745–748
10. Parr GR, Rueggeberg FA: In vitro hardness, water sorption, and resin solubility of laboratory-processed and autopolymerized long-term resilient denture liners over one year of water storage. J Prosthet Dent 2002;88:139–144
11. Jorgensen EB: Materials methods for cleaning denture. J Prosthet Dent 1979;42:619–623
12. Bollen CMD, Lambrechts P, Quirynen: Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: A review of the literature. Dent Mater 1997;13:258–269
13. Zissis AJ, Polyzois GL, Yannikakis SA: Roughness of denture materials: a comparative study. Int J Prosthodont 2000;13:136–140
14. Sexson JC, Phillips RW: Studies on the effects of abrasives on acrylic resins. J Prosthet Dent 1951;1:455–471
15. Murray D, McCabe JF, Storer R: Abrasivity of denture cleaning pastes *in vitro* and *in situ*. Br Dent J 1986;161:137–141
16. De Boer P, Duinkerke ASH, Arends J: Influence of tooth paste particle size and tooth brush stiffness on the dentine abrasion in vitro. Caries Res 1985;19:232–239
17. Eick JD, Craig RG, Peyton FA: Properties of resilient denture liners in simulated mouth conditions. J Prosthet Dent 1962;12:1043–1052