

Comparative Evaluation of Hardness and Energy Absorption of Some Commercially Available Chairside Silicone-Based Soft Denture Liners and a Heat-Cured Soft Denture Liner

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Aim: To investigate the hardness and energy absorption of four commercially available chairside types of silicone materials and compare their properties with heat-cured silicone material.

Materials: The chairside materials investigated were GC reline soft, mucopren soft, sofreliner soft and elite soft relining. The heat-cured polymer silicone material was Molloplast B. All soft lining materials were processed according to manufacturers' instructions. Two properties were investigated. Ten specimens for each test were prepared for each soft liner except for the water absorption and solubility test, for which only five specimens were prepared. The specimens of energy absorption (10 × 10 × 3 mm) were tested using a Lloyd instruments testing machine. Hardness specimens (38 × 38 × 3) were tested using a shore A durometer and were divided into two subgroups; dry and wet storage.

Results: The specimens of energy absorption (10 × 10 × 3 mm) were tested using a Lloyd instruments testing machine. Sofreliner soft was significantly softer than Molloplast B. GC reline soft was significantly harder than molloplast B. At high loads, sofreliner soft and elite soft relining was significantly more resilient than molloplast B. Mucopren soft was significantly stiffer than Molloplast B. At low loads, all materials showed similarities in stiffness and resilience; the difference between them was insignificant. After one month of immersion, GC reline and mucopren significantly increased hardness values.

Conclusion: In all conditions and at all four-time points, the hardness values for GC Reline soft were the greatest, and hardness values for Sofreliner Soft were the least. Some chairside soft denture lining materials could have similar significant properties to molloplast-B, such as sofreliner soft and elite.

Keywords: complete dentures, denture liners, hardness, polyvinyl siloxane liner, resilience, energy absorption, soft denture lining materials, stiffness

Background

Complete denture bases are made of hard acrylic resin to prevent distortions and fractures as they need to have sufficient physical and mechanical properties to withstand biting and chewing pressures.¹ However, due to a small layer of overlaying mucosa, some areas of the alveolar ridge are sensitive due to pressure from the underlying denture base. To make up for lost mucosal thickness and viscoelastic behaviour in these situations, it is required to line the inner part of the prosthetic material with a soft substance that mimics mucosa.²

Soft denture lining materials can create an absorbent layer on the portion of a denture that contacts the oral mucosa, which makes it possible for the transmission of fewer occlusal pressures. These materials that line dentures can help distribute forces more evenly by acting as a cushion on the inner surfaces of the denture base. Soft liners may also be advantageous for patients with alveolar bone resorption, bruxism, and severe undercutting in certain places^{3,4} and other conditions like xerostomia.⁵

Based on their composition, these liners can be divided based on materials (vinyl polysiloxane, silicone rubber and plasticized acrylic resin materials), short-term and long-term, room/heat temperature vulcanised, and other categories. The two main forms of most frequently used soft and durable lining materials are vinyl polysiloxane and silicone materials.⁶ Before the advancement of stronger silicones, polyvinyl chlorides were the most preferred material due to their great tensile strength, and excellent chemical and biomechanical properties in comparison with stiff materials like acrylic resin materials.^{3,7} The main issue with the acrylic product was the gradual loss of softness caused by plasticizers and other soluble chemicals thus making them less popular. Soft lining materials made of silicone have the benefit of becoming naturally soft over time and are the most widely used material. Due to the lack of a plasticizer, silicone liners outperform acrylic resin liners in terms of resilience and long-term cushioning maintenance.⁸

Soft denture lining materials are exposed to temperature variations in the oral cavity reducing the soft liner's mechanical characteristics like hardness and energy absorption. Flexural cyclic loads and thermal stressors, which are oral environmental factors, accelerate the deterioration and shorten the clinical life of relined denture bases. Dissolution occurs in the oral cavity that leaches unreactive monomer, irritating oral soft tissues.⁹

Previous studies of chairside silicone soft lining materials have usually included a larger number of materials, but these included a limited number of tests.¹⁰⁻¹³ This study has addressed unresolved issues in dental prosthetics of soft denture lining materials like comparison of shore hardness and energy absorption values amongst soft denture lining materials. Thus, this study investigated the hardness and energy absorption, of four commercially available chairside silicone long-term soft denture lining materials and compared some of their properties with that of a well-studied heat-cured silicone material (Molloplast B). The hypothesis of this study is that there are no significant differences in relation to hardness and energy absorption between the four chairside silicone denture lining materials with that of Molloplast B.

Materials and Methods

This in-vitro study investigated the hardness and energy absorption of four long-term denture chairside addition-cured vinyl polysiloxane materials (sofreliner soft, GC reline soft, mucoprotein soft, and elite soft relining) and one heat-cured silicone material (Molloplast B) as shown in Table 1. The vinyl polysiloxane materials were supplied as two-paste cartridge systems. Molloplast B was supplied as a single-component silicone. The processing of soft lining materials was made as per the manufacturers' directions. Ten specimens for each test were prepared for each soft liner except water

Table 1 Five Silicone Long Term Denture Soft Lining Materials, Their Types, Constituents, and Manufacturers

Material	Type	Chemical Components	Manufacturer
Mucopren Soft	Autopolymerized silicone	Vinyl polysiloxane, platinum catalyst, and others	Kettenbach GmbH Eschenburg, Germany
GC Reline Soft	Autopolymerized silicone Vinyl Polysiloxane	Silicone dioxide Vinyl dimethyl polysiloxane Hydrogen Polysiloxane	GC dental products, Kasugai, Aichi, Japan.
Soft liner	Autopolymerized silicone	Polyorganosilovane Silicone resin powder Silica, amorphous	Tokuyama Corp, Tokyo, Japan
Elite Soft Relining	Autopolymerized silicone	Polyvinylsiloxane platinum based catalysers	Zhermack SpA 45021 Badia Polesine (Rovigo) - Italy.
Molloplast-B	Heat-cured Silicone based.	Hydroxyl terminated Polydimethylsiloxane, fumed silica fillers, methyl triacetoxysilane, dibutyl tin dilaurate, PMMA	Detax GMBH Ettlingen/Germany.

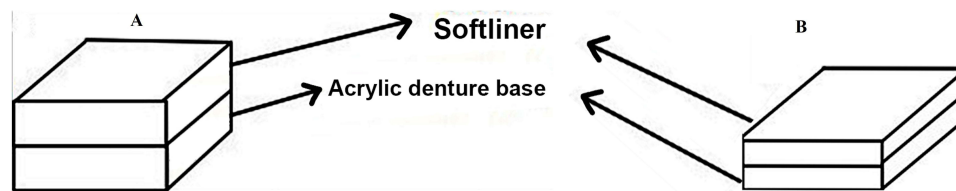


Figure 1 Diagrammatic representation of hardness (A) and energy absorption (B) specimen.

absorption and solubility test for which only five specimens were prepared. Properties like hardness values and energy absorption were investigated.

Hardness

Ten hardness specimens of $38 \times 38 \times 3$ mm of each soft lining material bonded to acrylic denture base resin of the same dimensions were prepared (Figure 1A). These specimens ($38 \times 38 \times 3$) were tested using a Shore A durometer and were divided into two subgroups; dry and wet storage. The acrylic resin used was Stellon Q-20 (Dentsply Ltd, Surrey, UK) and all chairside silicone soft liners were cured at room temperature. Molloplast B was cured for 7 h at 70°C with a terminal boil of 3 h at 100°C in the water bath. The hardness test was conducted according to ASTM D2240 (1984) specification for testing rubbery materials (Brown, 1988) using a Shore A durometer (Hampden Test Equipment Ltd, Northampton, England). The durometer was held to record the hardness reading after 1 second. Both groups of each material were then retested as above after 1 day, 1 week, 1 month and 3 months.

Energy Absorption

Ten energy absorption specimens of $10 \times 10 \times 3$ mm for each soft lining material bonded to the acrylic base of the same dimensions were prepared (Figure 1B). The acrylic resin used was Stellon Q-20 (Dentsply Ltd, Surrey, UK). The same procedure was used for all soft liners. All chairside silicone soft liners were cured at room temperature. Molloplast B was cured for 7 h at 70°C with a terminal boil of 3 h at 100°C in the water bath. Specimens were stored at room temperature before testing. Energy absorption testing was undertaken using a Lloyd Instruments Testing Machine (Lloyd Instruments, Southampton, UK) connected to a compatible computer. All specimens were compressed with 5 N, 10 N and 50 N loads. The rate at which the load was applied was 100 mm/min. The stiffness (N/mm) and resilience (J/mm^3) were automatically calculated from the following: Stiffness = Load (N) / Deflection (mm) and Resilience = Energy (J) / Volume (mm^3).

Statistical Analysis

Data obtained from the tests were analysed by Stata/IC v. 10.1 (Stata Corp LP, College Station, Texas, USA). Repeated-measures ANOVAs compared mean values of hardness for the five different materials to assess changes over time and any differences between wet and dry specimens. The Bonferroni test was done to determine differences between materials at two points. p-values of 0.05 or less were considered statistically significant. Initially, a one-way analysis of variance was used, with summary statistics being calculated (including mean, standard deviation, standard skewness, and standard kurtosis).

Results

Hardness

Table 2 and 3 show the hardness values in Shore A hardness units for five-silicone long-term denture soft lining materials at 24 hours, 1 week, 1 month and 3 months. GC Reline was the hardest material whereas Sofreliner was softest at all periods and conditions. Under the dry condition, GC Reline and Mucopren saw a significant increase in hardness after one month for the former and at one week for the latter ($p \leq 0.001$). Molloplast-B and Sofreliner saw a gradual decrease in their hardness values in the first half of the period and then a gradual recovery during the second half. Elite remained

Table 2 Shore Hardness Values of Dry Specimens (Mean \pm SD) Over 4 Periods of Time in Shore A Hardness Units (n=10 Dry/24h) (n =5 Days/1 Week, 1 Month, and 3 Months)

Material	Shore Hardness (Mean \pm SD) (n=10 Dry/24h)	Shore Hardness (Mean \pm SD) (n =5 Dry/1 Week)	Shore Hardness (Mean \pm SD) (n =5 Dry/1 Month)	Shore Hardness (Mean \pm SD) (n =5 Dry/ 3 Months)
Mucopren	46.7 \pm 1.5 (p \leq 0.001)	50.8 \pm 0.6 (p \leq 0.001)	50.5 \pm 1.2 (p \leq 0.001)	51.7 \pm 1.3 (p \leq 0.001)
Gc Reline	60.9 \pm 0.7	60.9 \pm 0.8	57.6 \pm 1.1 (p \leq 0.001)	59.9 \pm 1.4 (p \leq 0.001)
Soft liner	39.2 \pm 1.7	37.7 \pm 0.2	37.0 \pm 0.2	39.1 \pm 0.6
Molloplast-B	55.1 \pm 1.1	54.5 \pm 1.4	52.0 \pm 1.2	53.6 \pm 1.5
Elite	51.3 \pm 1.4	51.8 \pm 0.7	51.5	51.4 \pm 0.5

Table 3 Shore Hardness Values (Mean \pm SD) (in Distilled Water at 37C°) Over 4 Periods of Time in Shore A Hardness Units (n=5) (n =5 Dry/24h/1 Week, 1 Month, and 3 Months)

Material	Shore Hardness (Mean \pm SD) (n =5 Dry/24h)	Shore Hardness (Mean \pm SD) (n =5 Dry/1 Week)	Shore Hardness (Mean \pm SD) (n =5 Dry/1 Month)	Shore Hardness (Mean \pm SD) (n =5 Dry/ 3 Months)
Mucopren	51.5 \pm 0.4 (p \leq 0.001)	53.5 \pm 0.8 (p \leq 0.001)	55.4 \pm 1.0 (p \leq 0.001)	54.9 \pm 0.5 (p \leq 0.001)
Gc Reline Soft	60.0 \pm 0.6	61.1 \pm 1.4	62.5 \pm 2.2 (p \leq 0.001)	64.9 \pm 0.3 (p \leq 0.001)
Soft liner	40.1 \pm 1.7	38.7 \pm 1.0	37.4 \pm 0.8	39.8 \pm 0.8
Molloplast-B	55.1 \pm 0.7	54.5 \pm 2.1	53.5 \pm 0.6	53.8 \pm 0.4
Elite	53.0 \pm 1.6	51.7 \pm 1.8	52.6 \pm 1.7	53 \pm 0.84

stable over the whole period. After immersion, only GC Reline and Mucopren saw a significant change in their hardness compared to their dry counterparts.

After 24 hours of immersion, all materials saw no change in their hardness values except Mucopren which saw a significant increase. At a one-week period, immersion affected only the hardness values of Mucopren and GC Reline. Mucopren hardness values increased significantly while that of GC Reline increased not significantly.

At one month of immersion, GC Reline and Mucopren saw a significant increase in hardness values. At the end of the period, both GC Reline and Mucopren experienced a significant increase in their hardness values. In contrast, Molloplast-B, Sofreliner, and Elite saw no significant change between the two conditions at all periods. Thus, over the immersion period, only the values of Mucopren and GC Reline saw significant change. Their highest increase was in the first half of the period. On contrary, Molloplast- B, Sofreliner, and Elite were stable over the whole period of the study (Table 2 and 3).

Mean hardness values for wet and dry specimens of different materials at each of the four-time points are shown in the form of a graph in Figures 2 and 3. In all conditions and at all four-time points, the hardness values for GC Reline Soft were greatest and hardness values for Sofreliner Soft were the least. Other materials were intermediate in hardness value and were very similar to each other (Figures 2 and 3).

Energy Absorption

Energy absorption characteristics are given in Table 4. Loads of 5N, 10N, 25N, 35N, and 50N were applied. The results were recorded only for load 5N and 10N. At 5N and 10 loads, Mucopren and GC Reline showed the highest stiffness values (Low compliance). At 5 loads, they had 32.3 N/mm and 30.1N/mm respectively and at 10 load their values were 40.3 N/mm and 40.0 N/mm with no significant difference between them (p<0.05). Elite exhibited the lowest stiffness value of 23.0N/mm followed by Molloplast-B with 26.3 N/mm. No significant difference was found between their

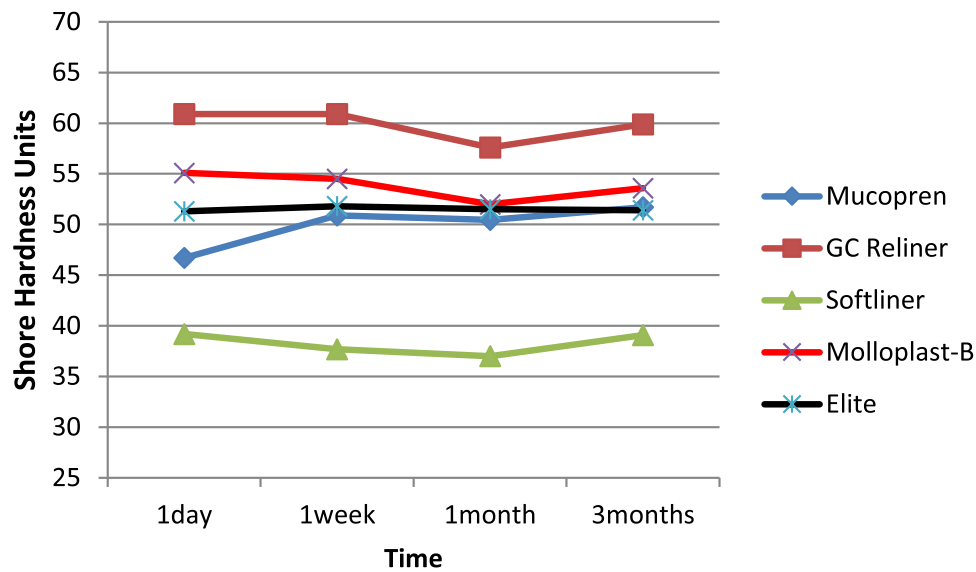


Figure 2 Shore hardness values of dry specimens (Mean ± SD) over 4 periods of time in Shore A hardness units (n=10 dry/24h) (n =5 dry/1 week, 1 month, and 3 months).

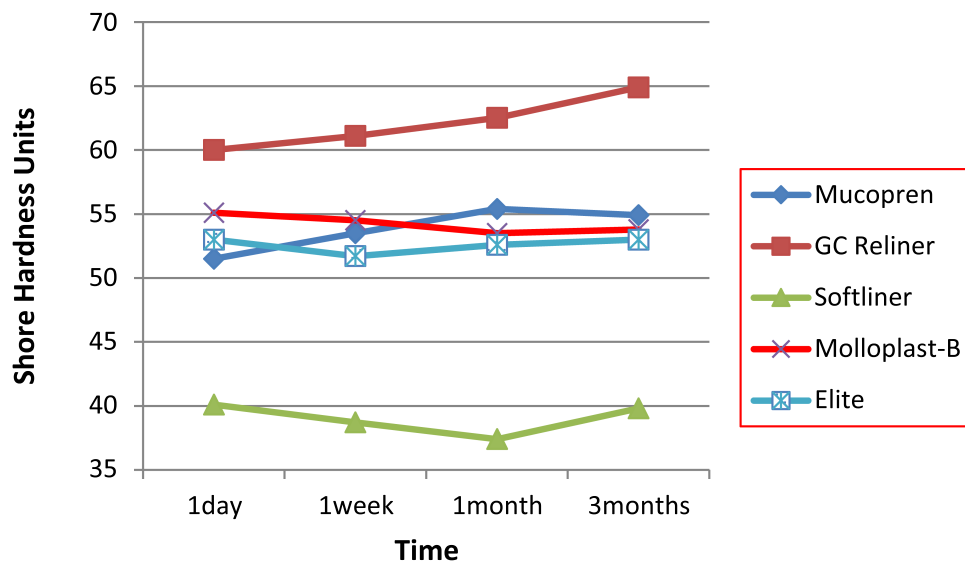


Figure 3 Shore hardness values (Mean ± SD) (in distilled water at 37°C) over 4 periods of time in Shore A hardness units (n=5) (n =5 dry/1 week, 1 month, and 3 months).

values. The value of Elite was not significantly different from the values of other tested materials except with Mucopren. From the statistical analysis, it was appeared that under all the applied loads there were no significant differences in stiffness values amongst five levels of materials except between that of Mucopren (32.3 N/mm) and Elite’s (23.0N/mm). On the other hand, resilience at 5N and 10N loads was inversely related to that stiffness. At both loads, Mucopren and GC Reline had zero resilience values. Elite and Molloplast-B experienced the highest values. Similarly, there were no statistically significant difference in the resilience values between the five levels of materials except between that of GC Reline (1.27J/mm³) and Elite’s (1.73J/mm³) (Table 4).

Fi-Index Tool

This manuscript has been checked with the Fi-index tool and obtained a score of 0 for the first author only on the date 15/03/2023 according to SCOPUS.^{14,15} The fi-index tool aims to ensure the quality of the reference list and limit any auto-citations.

Table 4 Energy Absorption-Related Values (Mean \pm SD) for Five Silicone Long-Term Denture Soft Lining Materials at Load 5N and 10N (n=10)

Material	Load at Limit (N) (n=10)	Stiffness (N/mm)	Young's Modulus (MPa)
Mucopren	5	32.3 \pm 13.2	9.21
	10	40.3 \pm 14.8	5.64
GC Reline	5	30.1 \pm 7.7 (p>0.05)	10.56
	10	40.0 \pm 10.5	2.34
Soft liner	5	27.7 \pm 6.3	5.07
	10	32.8 \pm 6.3	5.70
Molloplast-B	5	26.3 \pm 12.4	6.67
	10	46.9 \pm 38.5	4.42
Elite	5	23.0 \pm 6.5 (p>0.05)	3.8
	10	30.9 \pm 8.8	3.3

Discussion

Soft denture lining materials are frequently used to create all or part of a denture's intaglio surface and help repair injured tissues by serving as a temporary or long-term cushion in the therapeutic management of prosthodontic patients.^{3,6,9} These materials for dentures can assist distribute forces towards soft tissues when chewing more uniformly, reducing severe mechanical stress over underlying mucosa.^{16,17} Thus, we conducted this study to investigate the hardness and energy absorption of four commercially available chairside silicone long-term soft denture lining materials and compared some properties with heat-cured silicone material. Overall, the null hypothesis of this study is partially accepted in relation to some mechanical properties of chairside types of silicone denture lining materials with their properties with heat-cured silicone material.

Ten specimens for each test were prepared for each soft liner with the exception of the water absorption and solubility test for which only five specimens were prepared. Hardness specimens (38 \times 38 \times 3) were tested using a Shore A durometer and were divided into two subgroups; dry and wet storage of 5 specimens each. The first group of each soft denture lining material was placed in distilled water in glass containers at 37° C. The second group was kept dry in plastic containers at room temperature. Both groups of each material were then retested as above after 1 day, 1 week, 1 month, and 3 months. The specimens of energy absorption (10 \times 10 \times 3 mm) were tested using a Lloyd Instruments Testing Machine. All specimens were compressed with 5 N, 10 N and 50 N loads. All the specimens were tested on the same day and under the same temperature (22° C \pm 1C°).

Molloplast B was chosen for comparison as a heat-cured soft lining material because it has been widely studied and is well recognised for its good clinical performance. The physical tests were chosen to provide a broad range of information on the materials. Those tests may help predict the behaviour of those materials in the clinical situation. The hardness of a material may be measured in different ways. The Shore A durometer used in this study measures indentation resistance. It is suitable for use for rubber materials and has been used in several previous studies of soft denture lining materials.^{10,11,13,16-18} A four-week period was thought to be an adequate storage interval to show any change in the hardness values of these soft denture lining materials.⁹ The serviceability of soft lining material in a harsh oral environment is influenced by factors such as its hardness, strength, and energy absorption properties. These properties were considered particularly important and were selected for this study.^{13,17}

In our study, GC Reline Soft had the greatest hardness values and Sofreliner Soft had the least. GC Reline Soft, Mucopren Soft and Sofreliner Soft had significant changes over the whole period in both conditions. In contrast to the other silicone materials studied, GC Reline Soft demonstrated a significant increase in hardness over time, with the first 28 days recording the most significant rise. Our finding was similar to the study conducted by Bujak et al in 2021, wherein GC Reline Soft demonstrated a marked increase in hardness amongst all soft denture lining materials. They

carried out the study in a distilled water setting with a 90-day term ageing similar to our study.¹⁶ Another study by Sameeh et al in 2021¹⁹ also supported our results wherein they conducted a study comparing the surface hardness of two silicone based soft denture liners mainly Voco and Mollosil with three different denture cleansers (Periogard, Secure, and Polident). When compared to Voco soft liners with three different denture cleanser groups in the first week and first month, Mollosil soft liners demonstrated a highly significant increase in surface hardness. After six months, Voco soft liners outperformed Mollosil soft liners in all groups. This finding is confirmed by an in vitro investigation by Pahuja et al¹³ that found silicone-based soft liners performed significantly better than acrylic-based soft denture liners and with cleaning agents, thereby maintaining resilience better and more viable for long-term use. Thus, it may be said that silicone materials exhibit excellent hardness stability throughout time.

Białyżyt-Bujak et al¹⁸ examined how commonly used denture cleaning agents affected the surface hardness and toughness of acrylics and silicon-based liners over time. Two widely available denture cleansers, Polident and Efferdent Plus, were used to test two auto-polymerizing denture liners, Kooliner (acrylic) and GC reline soft (silicone). Shore A durometer and profilometer were used to measure surface hardness and roughness, respectively. The results showed that silicone-based liner material had a lower average surface hardness and surface roughness than acrylic liner material. This finding was similar to our study as we compared the hardness and energy absorption of silicone-based soft denture liners (GC Reline Soft, Mucopren Soft, Sofreliner Soft and Elite Soft Relining) with heat-cured soft denture liners (Molloplast-B). We also demonstrated similar findings that in all conditions and at all four-time points, the hardness values for GC Reline Soft were greatest.

Pahuja et al performed a systematic review in 2020 that included a total of 176 studies and examined the influence of several chemical disinfection procedures on the rise in surface hardness of silicone-based soft denture liners, concluding those acrylic-based soft liners showed a substantially higher increase in surface hardness than silicone-based soft liners. However, over time, silicone-based soft denture liners outperformed acrylic-based soft liners in terms of surface roughness and water sorption, surface hardness, and color stability.¹³ Regardless of the cleansing processes, the silicone materials' elastic characteristics did not change in comparison to acrylic material.

Mancuso et al²⁰ demonstrated contrary results to our study wherein they investigated the hardness and colour stability of denture liners based on acrylic resin and silicone after thermocycling. However, the hardness and colour stability of soft silicone liners were found to be less influenced than those of acrylic resin-based liners. Also, a study done by Chauhan et al in 2021 demonstrated contrary findings as hardness values for the heat-cured acrylic product were continuously higher than those for self-cured acrylic products. These findings were contrary to our results as we compared silicone-based soft denture liners to that of heat-cured soft denture liners.²¹

Research by Mutluay et al in 2017,²² changes in surface characteristics and softness of soft relining materials following cyclic loading were evaluated. Three proprietary polysiloxane denture liners mainly Silagum AM Comfort, Molloplast B, and Mollosil Plus, and two acrylic-based mainly Vertex Soft and Astron LC Soft relining materials, as well as a vinyl polysiloxane ie Imprint 2 Garant imprint substance, were examined. Shore A hardness values were also assessed. In comparison to acrylic resin-based plasticized materials, polysiloxane-based materials retained their softness, surface roughness, and surface smoothness better during cyclic loading. This finding was similar to our research wherein the polyvinyl siloxane materials, Mucopren and GC Reline showed the highest stiffness values whereas Elite exhibited the lowest stiffness value followed by Molloplast-B. In our study, we have shown that, at both loads, Mucopren and GC Reline had the lowest resilience values whereas Elite and Molloplast-B experienced the highest values.

In this study, different silicone denture liner materials have been used with similar components but maybe different cross-linking, polymers and filler properties. It is, therefore, clear that the choice of silicone material can influence the hardness and energy absorption properties based on components. A higher cross-linking density and lack of appropriate silica fillers such as that in Mucopren and GC Reline results in a harder material with reduced energy absorption. The effectiveness of silicone soft lining materials can also be impacted by environmental factors like moisture absorption. The findings of this research indicate that the selection of the material is of greater significance compared to the environmental conditions. This observation underscores the clinical importance of maintaining proper moisture balance when storing a relined denture to prevent the uncomfortable drying out of denture lining materials, which can result in discomfort for the wearer and potentially contribute to alterations in oral tissues.

There have been several limitations to this study. Firstly, it has been carried out in the laboratory where caution should be taken into consideration when applying and interpreting its results in clinical situations. Secondly, if soft denture lining materials were to be examined for deforming forces, dynamic cyclic forces might be appropriate to be used in simulating mastication forces experienced in the clinic rather than a compression test.^{23–26} The compression set test does not represent mastication forces due to the great energy input directed at the soft liner within a long duration of load which gives the material a poor recovery response compared to dynamic and cyclic behaviour under masticatory forces.

Also, soft denture lining materials are made to fit over dentures while they are worn in the mouth. It is not entirely accurate to compare the in vitro character of this study to the nutrient-rich environment of the oral cavity. The behaviour of the denture liner materials in this study may thus only partially predict clinical performance. Even though the use of soft denture liners in prosthetic dentistry has risen, more research is still needed on aspects including solubility, surface roughness, binding strength, color stability, thermocycling, and viscoelastic characteristics.

Conclusions

Based on the study findings it can be concluded that some chairside denture soft denture lining materials could have equivalent significant properties to Molloplast-B such as Sofreliner Soft and Elite as follows: Sofreliner Soft was significantly softer than Molloplast B. At high loads, Sofreliner Soft and Elite were significantly more resilient than Molloplast B. At low loads, all materials showed similarities in stiffness and resilience and the difference between them was not significant.

Disclosure

The authors report no conflicts of interest in this work.

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