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A COMPARATIVE EVALUATION OF SHEAR BOND STRENGTH BETWEEN DIFFERENT SOFT LINERS TO HEAT-CURED ACRYLIC RESIN VERSUS 3D PRINTED DENTURE BASES (AN IN-VITRO STUDY)

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ABSTRACT

Introduction: It is crucial to study the interaction between chairside softliners and the most recent denture base materials, as it is vital in ensuring optimal results.

Objective: To compare the shear bond strength of two chairside softliners using traditional heat-cured acrylic resin and innovative 3D-printed denture base resin material.

Materials and Methods: 80 specimens with 50 x 10 x 3 mm dimensions were produced. The specimens were classified into two groups (n = 40) based on the type of denture base material used: heat-cured acrylic resin and 3D-printed resin. Each group was divided into two subgroups (n = 20), resulting in ten pairs (n = 10) per subgroup. The subgroups were distinguished based on the type of soft-liner material bonded to the denture base: subgroup A used a silicon-based soft liner, while subgroup B used an acrylic-based soft liner.

Results: According to the study, the group that used heat-cured PMMA (Group I) had a significantly higher shear bond strength of (0.632 MPa) compared to the 3D printed group (Group II) with a shear bond strength of (0.397 MPa). Moreover, the silicon-based soft-liner subgroups had a slightly higher shear bond strength (0.566 MPa) than the acrylic-based soft-liner subgroups (0.463 MPa). However, this difference was not statistically significant.

Conclusion: Heat-cured acrylic resin material showed higher shear bond strength than 3D-printed resin material. The silicone-based soft liners had better shear bond strength than the acrylic-based soft liners.

KEYWORDS: 3D printed dentures, Chairside soft-liners, Shear Bond Strength

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INTRODUCTION

A fundamental objective of dental patient care is to guarantee optimal functionality and satisfaction while utilizing the dental prosthesis. This objective can be achieved through the implementation of a relining procedure, which has the potential to mitigate pressure areas effectively, enhance prosthesis retention through the utilization of undercuts, and distribute stress uniformly across the denture-bearing areas [1].

Immediate dentures following extractions to treat inflamed mucosa, obturators used after maxillofacial surgery, and temporization following immediate implantation are all situations where these liners could be helpful [1]. The most significant problems with soft denture liners are their porosity, lack of tear strength, and loss of softness, all of which make them prone to adhesion failure between the denture base and the liner. This adhesive failure creates a perfect environment for bacteria and plaque growth [2,3].

To guarantee the longevity of soft denture lining materials, ensuring their durable attachment to the foundation is essential. Therefore, the bond between the soft liner and denture base is vital for optimal performance. The liner type and denture foundation material determine their cohesion to the denture base [4].

Until recently, heat-activated polymethylmethacrylate (PMMA) resin was the prevailing material used for denture bases. This resin is typically produced via compression, injection, or injection molding techniques. However, the heat-activated PMMA resin experiences an approximate 7% volumetric reduction [5-7]. In recent times, thanks to the advancements in CAD/CAM technologies, the polymethylmethacrylate resin can be produced using two methods: additive manufacturing, where it is 3D printed, or the subtractive approach, where it is milled from a pre-polymerized acrylic resin disk [6].

Additive manufacturing, also known as 3D printing, offers several benefits over milling procedures. Firstly, it can produce objects of any size or complexity, even those with bone undercuts, which is impossible with milling. Additionally, additive manufacturing produces less waste than milling and can precisely duplicate intricate features. [6] Moreover, additive manufacturing follows a passive production method, requiring no application of force throughout the manufacturing process. In contrast, milling can generate surface cracks through cutting burs and grinders during harsh machining [7,8].

In light of the extensive use of digital technology, it is crucial to compare the shear bond strength between the traditional approach of heat-cured acrylic resin and the innovative technique of 3D-printed dentures. Notably, there is a significant lack of studies examining the adhesive strength between soft-liners and 3D-printed denture bases [9]. Therefore, this study aims to evaluate the shear bond strength of chairside soft lining material with the traditional heat-cured and 3D printed denture base utilizing various chairside soft relining materials.

AIM OF THE STUDY

The research compared the shear bond strength of different types of chairside soft relining materials with the heat-cured polymethylmethacrylate denture base and the 3D-printed denture base resin.

MATERIALS AND METHODS

Study design:

Two types of chairside self-cured relining materials were used. Eighty specimens were prepared in total, as 40 specimens were prepared from each denture base material, 20 for each subgroup to create ten pairs per subgroup, as follows:

Group I: Heat-cured acrylic resin denture base:

- Subgroup I-a: Heat-cured acrylic resin denture base (VertexTM-Dental B.V- Netherlands), with silicone-based soft-liner (Mucopren soft – Kettenbach GmbH - Germany).

- Subgroup I-b Heat-cured acrylic resin denture base with acrylic-based cross-linked soft-liner (Acrostone soft – Acrostone - Egypt).

Group II: 3D printed denture base:

- Subgroup II-a: 3D printed denture base (NextDent Denture 3D+, NextDent B.V., The Netherlands) with the silicone-based soft-liner.
- Subgroup II- b: 3D printed denture base with acrylic-based cross-linked soft-liner.

Test samples preparation:

Virtual designing of the specimens

The specimen blocks were created using a free computer-aided design (CAD) software program (Meshmixer, Autodesk, Inc.). Two rectangular specimens were designed digitally. The first specimen was of dimensions approximately 50 x 10 x 3 mm, similar to the surface area of a denture. The second one was of dimensions 10 x 10 x 3 mm, identical to the typical thickness of the soft-liner substance, as shown in Figure 1.

Fabrication of 3D-printed denture base resin specimens

Forty specimens of denture base material were 3D printed from a resin of the final denture base. The resultant samples were removed from the printer platform (Creality Halot - China) (figure 1-b), immersed in alcohol (95%), and then placed in an ultrasonic washer for three minutes to remove any excess resin then the process was repeated for another two minutes. The total cleaning time in alcohol should not take longer than 5 minutes, as the manufacturer prescribes. Finally, they were placed in the UV curing device (AnyCubic- China) for 30 minutes to complete the final curing and ensure optimal polymer conversion.

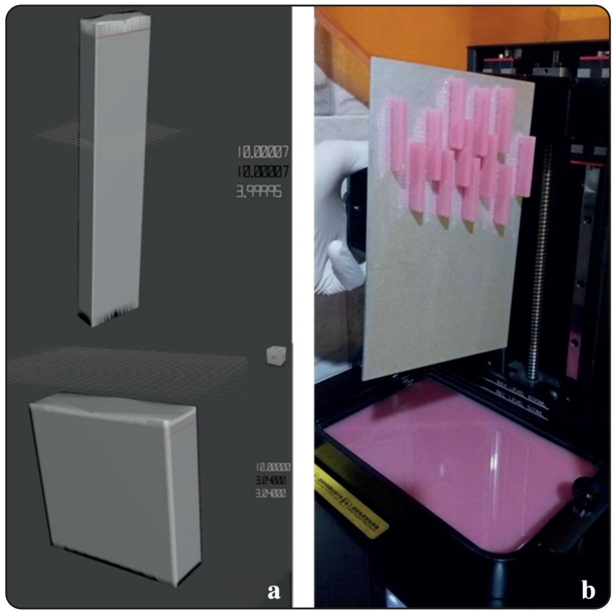

Fig. (1) a) Virtual design of the specimens on the software b) 3D printed specimens from the denture base resin

Fabrication of heat-cured acrylic resin denture base specimens

Forty specimens were fabricated using 3D printing technology with temporary resin material (Proshape Temp Resin, Turkey). Molds of gypsum were then created for the specimens, which were filled with molten wax (Cavex BV Netherlands) after removing the temporary resin blocks. The wax was allowed to harden, followed by classic flasking and wax elimination. Next, the heat-cured acrylic resin was packed and cured using conventional denture processing methods. Finally, the specimens were removed from the flask, necessary steps were completed, and the specimens were refined to a smooth and shiny finish.

Application of soft liner

The spacer blocks were affixed between each pair, and then the pairs were submerged in a gypsum mixture within the flasks and left to dry. The purpose of the spacer block was to provide room for the soft lining material after it was removed. Before injecting the soft-liner, the specimens were cleaned and dried after removing the spacer. The soft-liners were prepared according to the manufacturer's instructions. The adhesive was applied in two layers for the silicon-based soft-liner (Mucopren) and allowed to dry. Then, the Mucopren was injected into the spaces, and the two compartments of the flask were closed tightly to ensure sufficient pressure and complete distribution of the material. This was left undisturbed for 10 minutes, after which the flasks were placed in a warm water bath at 50°C for an additional 15 minutes. Subsequently, the flasks were unsealed, and any excess material was eliminated. Finally, a layer of silicon sealer was added to improve the adhesion procedure.

The acrylic-based soft-liner was prepared by mixing the powder and monomer and then injecting the mixture into its designated places. The flask compartments were closed to allow the material to disperse fully within its space. After the material was set, which took roughly 5 minutes, the flasks were opened, as shown in Figure 2.

Thermocycling techniques for dental restoration laboratory testing:

The test was conducted via a thermocycling system (Robota automatic thermal cycle, BILGE, Turkey). The following stages were performed: A total of 3000 cycles were utilized, equivalent to 12 months under real-life use. There was a 10-second delay between each 25-second interval in the water bath. The temperature ranged from -5°C to 55°C [10] Figure 3.

Specimens' testing

Shear Bond Strength test with Area:

Test process

A square-shaped interface shear test was devised to assess the bond strength. The samples were mounted on a computer-controlled materials testing machine (Model 3345; Instron Industrial Products, Norwood, USA) with a load cell of 5 kN. Data were obtained using computer software (Bluehill Lite; Instron Instruments). The samples

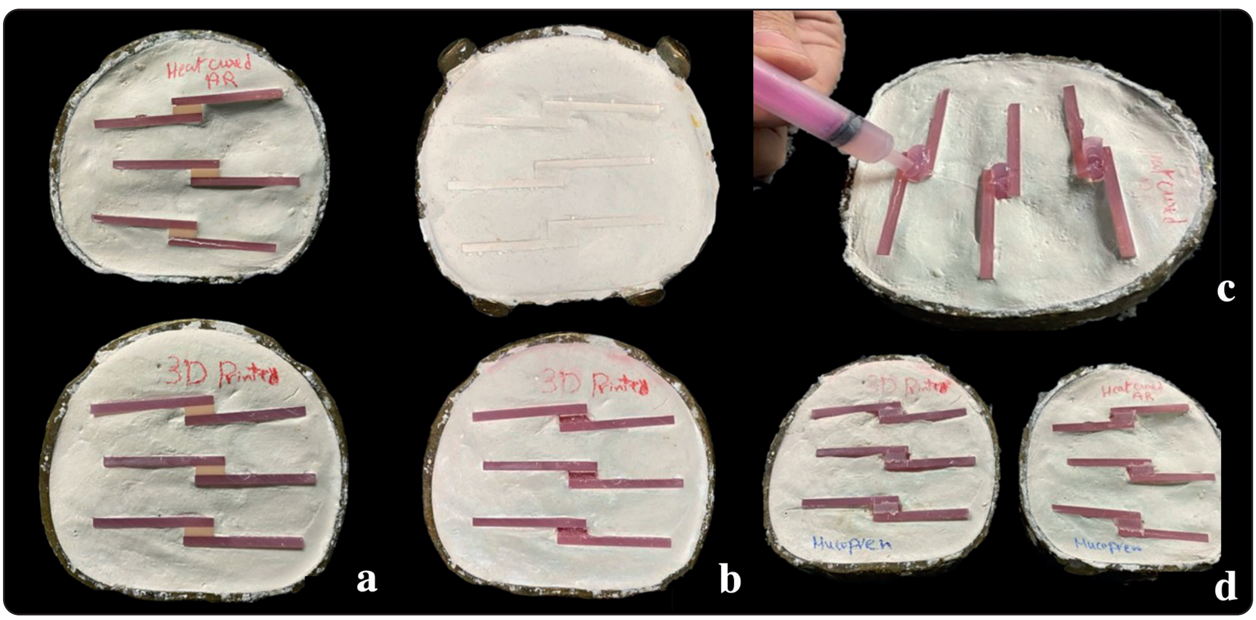

Fig. (2) a) Specimens secured in the flask with the spacer b) Specimens after spacer removal c) Injection of the soft-liner between the specimens d) Soft-liner after complete curing.

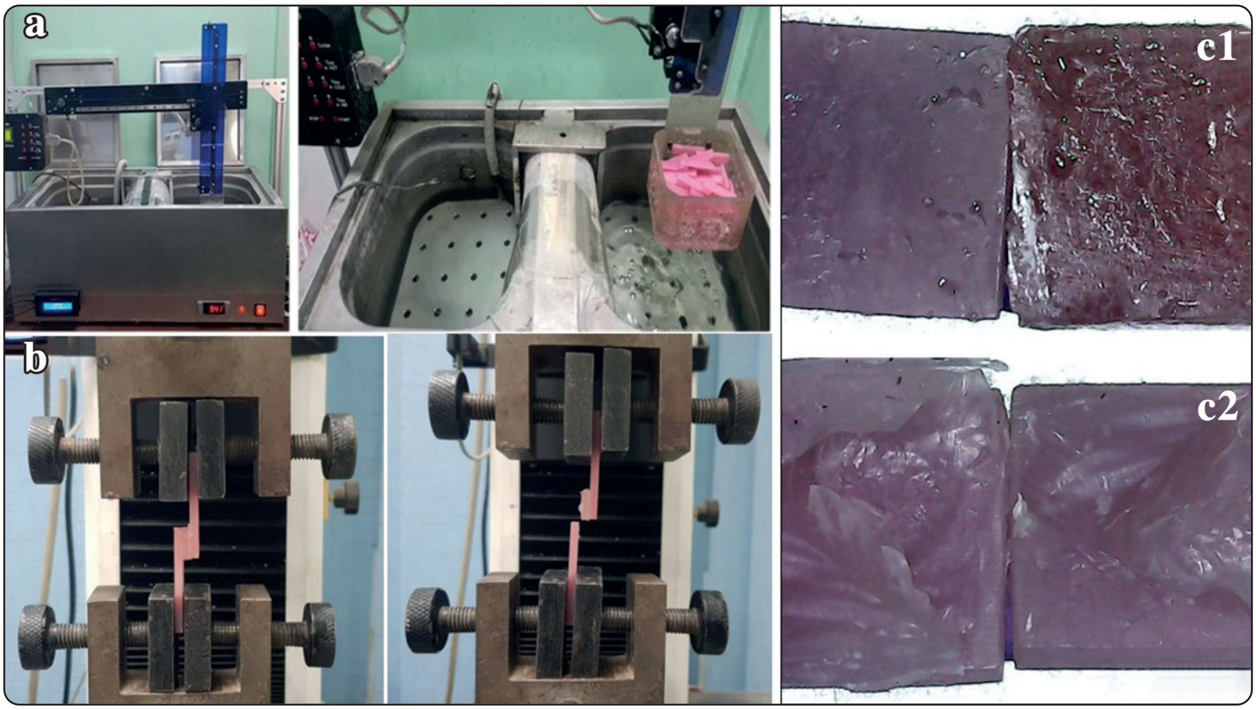

Fig. (3) a) Thermal ageing of the specimens. b) Shear Bond Strength test. c 1) Representative digital microscopic image for adhesive failure mode pattern. c 2) Representative digital microscopic image for mixed failure mode pattern.

were securely held in place using a sample holder that was attached to both the upper movable and lower fixed compartments of the testing machine by tightening screws. The shearing test was conducted using the pull-out mode of load application on the Instron testing machine, with a 50 mm/min cross-head speed. The load needed for de-bonding was measured in Newtons, as shown in Figure 3.

Failure mode pattern

Using a USB digital microscope (U500x Digital Microscope, Guangdong, China), failure modes were observed and documented at a fixed magnification 25x, as shown in Figure 3(c). Upon careful analysis of the various failures, they were classified into three modes: cohesive failure: failure in the relining material, adhesive failure: failure at the interface (no visible traces of reline material on the specimen), and combination failure: a combination of both adhesive and cohesive

RESULTS

The data were displayed in the form of the mean, standard deviation (SD), 95% confidence intervals (CI), and the minimum and maximum values. The data were examined for normality by applying the Shapiro-Wilk and Kolmogorov-Smirnov tests to the data distribution. A comparison was made between coupled and unpaired groups using a student t-test. A two-way ANOVA was conducted to determine the impact of each factor (material group and aging) on the shear bond and hardness outcomes. The chi-square test was applied to distinguish failure mode patterns. With a confidence level of 95% and a sample size of 10 per subject, the study could identify significant effect sizes for main effects and pair-wise comparisons, with a level of power deemed satisfactory at 80%. The statistical analysis was conducted utilizing the Graph Pad Instat software for Windows, developed by Graph Pad, Inc.

Shear bond strength test results (MPa)

The mean and standard deviations of shear bond strength test results (in MPa) for both groups, before and after thermal aging, are presented in Table (1) and graphically in Figure 4.

- Comparison of Shear bond strength (MPa) results between groups with acrylic-based soft-liner subgroup:

The Heat-cured group (Group I) exhibited a higher mean shear bond strength value (0.531 MPa) compared to the 3D printed group (Group II) (0.395 MPa). This difference was statistically significant, as shown by an unpaired t-test (P=0.0194 < 0.05), as described in Table (1) and Figure 4.

- Comparison of Shear bond strength (MPa) results between groups with silicon-based soft-liner subgroup:

The Heat-cured group (Group I) had a greater mean shear bond strength value (0.7329 MPa) compared to the 3D printed group (Group II) (0.398 MPa). However, this difference was not statistically significant according to the unpaired t-test (P=0.1084 > 0.05). The data can be seen in Table (1) and Figure 4.

- Comparison of Shear bond strength (MPa) results between liner subgroups within each denture base material:

TABLE (1) Shear bond strength results (Mean values ±SDs) for both groups with different liner after thermal ageing

Variable		*Liner type*								*Statistics*
		Acrylic-based soft-liner				*Silicon-based soft-liner*				
		Mean	*± SD*	*95% CI*		*Mean*	*± SD*	*95% CI*		*t-test*
				Low	*High*			*Low*	*High*	*P value*
Material group	*3D printed*	0.3952	0.014	0.383	0.407	0.398	0.128	0.286	0.51	0.9609 ns
	Heat cured	0.531	0.103	0.44	0.622	0.7329	0.394	0.387	1.078	0.3002 ns
Statistics	*t-test*	*P value*		0.0194*		*P value*		0.1084 ns		

; significant (p<0.05) ***ns ; non-significant (p>0.05)***

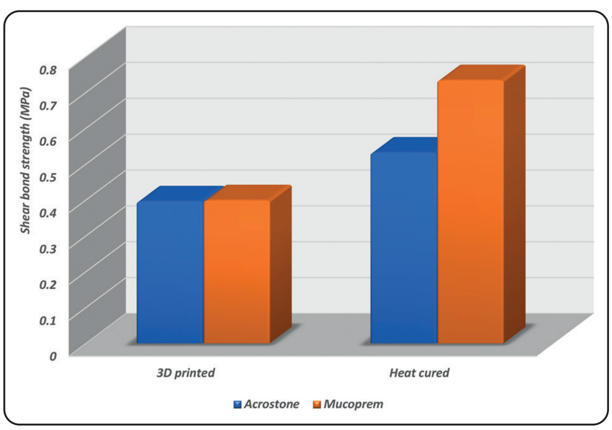

Fig. (4) Column chart of the mean values of shear bond strength for both groups with different liner after thermal ageing

The heat-cured group (Group I) showed a greater mean shear bond strength value (0.7329 MPa) compared to the acrylic-based soft-liner subgroup (0.531 MPa) in a statistically non-significant manner. This was validated by a paired t-test (p=0.3002 >0.05), as presented in Table 1 and Figure 4.

The 3D printed group (Group II), consisting of the silicon-based soft-liner subgroup, exhibited a slightly higher mean shear bond strength value (0.398 MPa) compared to the acrylic-based soft-liner subgroup (0.395 MPa). This difference was statistically non-significant based on the paired t-test results (p=0.9609 > 0.05). These findings are presented in Table (1) and Figure 4.

- Total effect of material group on Shear bond strength mean value:

Irrespective of the type of soft-liner, the Heat-cured group (Group I) exhibited a higher mean shear bond strength value (0.632 MPa) compared to the 3D-printed group (Group II) (0.397 MPa). The difference between the two groups was statistically significant, as confirmed by the two-way ANOVA test (p=0.01<0.05).

- Effect of liner on Shear bond strength mean value:

Regardless of the material groups, the silicon-based soft-liner subgroups showed a statistically insignificant higher mean shear bond strength value (0.566 MPa) compared to the acrylic-based soft-liner subgroups (0.463 MPa), as indicated by the two-way ANOVA test (P=0.2416 > 0.05).

Failure mode pattern

The evaluations were conducted using three modalities specified in Table (2) and depicted in Figure 3. All samples from the Acrylic-based soft-liner subgroups had a 100% occurrence of adhesive failure, with no instances of mixed or cohesive failure patterns recorded (0%). Furthermore, the Silicon-based soft-liner combined with the 3D printed group exhibited a pattern of merely adhesive failure (100%). In contrast, the heat-cured group predominantly displayed an adhesive failure mode pattern (75%), with a smaller proportion of samples showing a mixed failure mode pattern (25%), and no instances of cohesive failure mode pattern (0%) were recorded. The chi-square test (p=1>0.05) showed no statistically significant difference in the failure mechanisms between both groups using the Acrylic-based soft-liner, as shown in Table 2. The failure modes between both groups with Silicon-based soft-liner showed a significant statistical difference, as determined by a chi-square test (p=<0.0001< 0.05), as presented in Table (2). The failure modes of the liner subgroups using Silicon-based soft-liner were not statistically significant (p=1> 0.05) in the 3D printed group. Still, they were significant in the heat-cured group according to the chi-square test (p=<0.0001< 0.05), as shown in Table (2).

TABLE (2) Frequent distribution (%) of failure modes recorded for both groups before and after thermal ageing.

Variables		*Failure modes*						*Statistics*
		Acrylic-based soft-liner			Silicon-based soft-liner			*Chi test*
		Adhesive	*Mixed*	*Cohesive*	*Adhesive*	*Mixed*	*Cohesive*	*P value*
Material group	*3D printed*	100%	0%	0%	100%	0%	0%	1 ns
	Heat cured	100%	0%	0%	75%	25%	0%	<0.0001*
Statistics	*Chi test*		1 ns			<0.0001*		

; significant (p<0.05) ***ns ; non-significant (p>0.05)***

DISCUSSION

Accelerated bone loss often occurs within the first several months after tooth extraction. During this time, soft relining of the dentures for new denture wearers provides effective fit and increased comfort. Soft relining of dentures is preferred over hard relining in such situations because it may be done multiple times chair-side using commercially available acrylic- or silicone-based soft reline materials. Though one of the main issues with relined dentures is the detachment of soft liners from the denture bases, for the denture liner material to be clinically successful, there must be a strong bond between the two materials [11].

Recently, the dental market has introduced new denture base materials, such as 3D printed denture base resins, which have brought numerous benefits to the current production methods in dentistry. It also provides innovative research ideas in laboratory and clinical settings; nevertheless, these materials' chemical, biological, physical, and mechanical properties are still under investigation [12,13]. Furthermore, numerous factors can impact the quality of the printed resin used for the denture foundation. These factors include the composition of the material, the wavelength and power of the light used, the duration of post-curing, and the temperature during post-curing [14]. Thus, following the manufacturer's instructions for each resin material is essential.

Also, the adhesion between soft-liners and denture base resins is affected by various factors, such as the chemical composition of the materials employed, heat conditions in the mouth, the thickness of the soft-liner, the form of bonding, and the tear strength of the soft-liner [15,16]. However, there has been limited research on the adhesion between denture lining material and digitally generated denture bases, particularly in rapid prototyping [17].

While laboratory evaluation and in vitro investigations cannot perfectly replicate the conditions found in the oral cavity, such as the clinical environment, moisture, and stresses on teeth and dental restorations, they can partially simulate the oral cavity environment by subjecting teeth or restorations to thermal cycles (aging) procedures. Consequently, experimental research strives to be as similar as possible to the results achieved in clinical situations involving complicated circumstances inside the mouth [10].

The objective of this study was to thoroughly examine and determine the shear bond strength of two types of soft-liners (acrylic-based soft liner and silicone-based soft liner) used in conjunction with two different denture base materials (heat-cured acrylic resin (Group I) and 3D-printed denture base resin (Group II).

The null hypothesis was that there would be no significant difference in the shear bond strength between the two denture base materials after relining. However, the results of the study demonstrated that the heat-cured acrylic denture base material had a considerably higher average shear bond strength (0.632 MPa) than the 3D-printed denture base (0.397 MPa) regardless of the soft-liner group, and the difference was statistically significant; thus, the null hypothesis was positively rejected.

Furthermore, it was observed that the heat-cured acrylic denture base material (Group I) had a higher average shear bond strength value (0.7329 MPa) compared to the 3D printed denture base (Group II) (0.398 MPa) with the silicone-based soft liner (Subgroup I-a). However, this difference was not statistically significant. The results are in line with previous research that compared the shear bond strength of relined 3D-printed denture resins to that of relined heat-polymerized denture resins using comparable soft-liners [18-21].

The difference in outcomes between the two groups in this study can be confidently attributed to dissimilarities in the chemical composition of the two denture bases. This is likely since the soft-liner materials are compatible with the heat-cured acrylic resin denture base, as both materials share similar chemical structures [11,16,22].

The specimens of the heat-cured acrylic resin denture base material are made of poly-methyl methacrylate, whereas the printed denture base resin is made of bisphenol-A dimethacrylate, with additives to aid in light polymerization; thus, it's possible that the typical methyl methacrylate cross-linking that takes place across PMMA interfaces isn't happening in this group. This significant element could have contributed to the low shear bond strength. Besides, the 3D printed specimens must be placed in a curing unit as a final step in the manufacturing process. They may impact its surface energy and mode of bonding with any relining material [23].

Thermocycling simulates the conditions inside the mouth, and it can modify the shear bond strength of the denture by exposing it to different heat stresses. Thermal cycling deteriorates denture polymers in a humid environment, and water absorption may rise as the spacing between polymer chains expands due to heat strain [24]. The absorption of water is intimately linked to the dimensional instability of the dental material. Water absorption may affect the mechanical properties of dentures by functioning as a plasticizer, causing them to become softer and more elastic. This, in turn, may reduce the level of adhesion and can affect the functionality of relined removable prostheses. Exposing soft liners to thermocycling can have either a positive or negative effect on shear bond strength. However, most studies show a significant drop [25,26].

Another investigation found that thermocycling reduced the microhardness of denture base materials, resulting in lower shear bond strength with the lining materials. The chemical structure of 3D-printed resin differs from that of the conventional heat-cured acrylic PMMA resins, which could explain the observed change. Differences in thermal expansion coefficients between the relining material and the denture base resin might result in variable amounts of shrinkage and expansion. This causes cyclic tension at the contact, leading to increased bond fatigue during thermocycling [27].

Regarding the soft-liner material, the results revealed that despite the denture base material groups, it was shown that the silicone-based soft-liner subgroups recorded a statistically non-significant greater shear bond strength mean value (0.566 MPa) than the acrylic based soft liner ones (0.463 MPa). This finding was supported by a prior study that found that silicone-based soft-liners tightly bonded to conventional PMMA denture bases and performed better than acrylic-based soft-liners [28].

Furthermore, it was found that silicon-based liners had a better adhesive bonding system regardless of their chemical composition differences, which they attributed to the silicon's ability to penetrate deeply into the increased molecular weight and cross-linked denture resins. Also, the presence of volatile solvents in the chemical composition of the silicone-based polymer's adhesive system enhanced the bonding quality of silicone-based lining material to denture resin [29]. Regardless of the chemical similarities between the heat-cured PMMA and the acrylic-based soft liners, this study found that the acrylic-based soft liners had poorer bonding strength to the PMMA resin than the silicon-based soft liners; this could be due to the dense cross-linked resin that prevented the monomer from adequate penetration[30].

The failure mode pattern is a critical factor as it impacts the assessment of bonding strength test outcomes. The study findings indicate that the failure mode was predominantly adhesive (100%). This implies that the material's intrinsic strength exceeded the strength of its adhesive contact. However, in subgroup I-a, the heat-cured denture base with silicon-based soft-liner displayed a mix of failure modes in the specimens (75% adhesive and 25% cohesive). This could be attributed to the strong bonding between the heat-cured acrylic resin specimens and the silicon-based adhesive agent, as well as the soft nature of the soft liner, which led to cohesive failure upon pulling. This finding is consistent with another study that found that stronger binding is often accompanied by changes in how failures occur [21,31].

CONCLUSION

The study's results indicate that the soft liners exhibit significantly higher shear bond strength with the heat-cured acrylic resin material than the 3D-printed resin material. Moreover, the silicone-based soft liner outperforms the acrylic-based soft liner regarding shear bond strength.

Recommendation

The use of soft-liners with 3d printed denture base resins is clinically applicable. However, it is advisable for short-term usage.

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Regulatory statement

The ethical committee of Misr University for Science and Technology in Giza, Egypt (2022/0070) approved the investigation, and there are absolutely no ethical concerns.

Conflict of interest

The authors declare no potential conflicts of interest concerning this article's research, authorship, and/or publication.

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