Due to surgical or financial problems, some patients with removable dental prostheses are unable to undergo preprosthetic surgery and/or implant placement and therefore require a soft liner to prevent mucous irritation and injury under the denture. The soft liner is a material applied to the tissue surface of the complete or partial dentures to reduce the pressure on the atrophic bone induced by chewing. The liner can also be used to improve the fit and comfort of a denture, especially immediate dentures. The clinical success of a soft liner depends on its ability to retain its shape and adapt to the ridge after initial pressure is applied.

Soft liner materials are generally divided into two groups according to durability: short term and long term. Permanent (long-term) soft liners are beneficial for patients with persistent pain under the denture, thin atrophic mucosa, and resorbed...
knife-edged alveolar ridges, especially in the mandible. They are also useful for rebasing or relining the denture, increasing the retention of an intraoral maxillofacial prosthesis.\textsuperscript{3,5}

According to chemical structure and processing method, permanent soft liners are most commonly considered to be in two groups: acrylic resin and silicone rubber, and both can be either chemically activated or heat activated. The heat-activated acrylic resin soft liner (eg, AcroSoft, Vertex Soft) is characterized by satisfactory and durable bonding with the denture base and a high tear and abrasion resistance. In addition, it is more highly polished than the silicone liners.\textsuperscript{3,5} This soft liner is a polymer whose glass-transition temperature is lower than the oral temperature.\textsuperscript{5} The excretion of its components in the oral environment is this liner’s major drawback.\textsuperscript{3,5} The chemically activated acrylic resin soft liner is used chairside; however, its tendency to separate from the base within a few weeks limits its clinical use.\textsuperscript{3,5}

Silicone rubber liners have gained significant success in terms of flexibility and long-term elasticity. Their critical drawback is the loss of adhesion to the base of the denture, especially at the border of the base.\textsuperscript{5} Heat-activated silicone soft liners (PermaFlex, Flexor, Luci Soft, and Molloplast-B) can be processed alongside polymerized denture-base acrylic resin. Chemically activated silicone soft liners (room-temperature vulcanizing liners) have fewer cross-links than heat-activated liners, which can diminish their long-term properties.\textsuperscript{5-7}

In previous studies, methods for acrylic resin denture base surface treatments have been divided into mechanical and chemical.\textsuperscript{8} Common mechanical treatment methods include grit blasting and laser application. Grit blasting is controversial, as several studies have shown that grit blasting significantly reduces tensile strength.\textsuperscript{9-12} One study showed a nonsignificant increase in tensile bond strength with grit blasting,\textsuperscript{13} while Usumez et al reported that the alumina air-abrasion group had significantly higher tensile strengths than those without surface preparation and compared to the laser preparation groups.\textsuperscript{14} In several studies, various kinds of lasers have been used for acrylic resin denture base surface treatment. A carbon dioxide (CO\textsubscript{2}) laser was used to create a grid design and resulted in a lower tensile strength than that of the group without preparation.\textsuperscript{9,14} An erbium:yttrium-aluminum-garnet (Er:YAG) laser significantly increased the bond strength between the soft liner and denture base, while neodymium-doped yttrium aluminum garnet (Nd:YAG) and potassium titanyl phosphate (KTP) lasers were ineffective and did not increase bond strength.\textsuperscript{11} Preparing with erbium, chromium-doped yttrium, scandium, gallium, and garnet (Er,Cr:YSGG) lasers have advantages in terms of 3-W and 20-Hz parameters.\textsuperscript{13}

Chemical surface treatments with different chemical agents improve bond strength and reduce leakage. The use of a methyl-methacrylate monomer for 180 seconds was the most effective type of chemical preparation.\textsuperscript{12,15} Acrylic resin denture base surface treatment with methyl-methacrylate and ethyl-methacrylate reinforces the bonding of the silicone liner to poly(methyl methacrylate) (PMMA).\textsuperscript{16} Akin et al found that immersion in isobutyl methacrylate for 3 minutes resulted in a tensile bond strength between the soft silicone liner and denture base acrylic resin that was twice that of the group without this preparation.\textsuperscript{17} Gundogdu et al demonstrated that adapting the acrylic resin surface with 36% phosphoric acid etching increases bond strength.\textsuperscript{18}

Simultaneous (synchronous) processing of denture base acrylic resin and heat-activated soft-liner materials (PermaFlex, Flexor, Luci Soft, and Molloplast-B) in which the soft liner is packed against the PMMA dough is recommended for better bonding than when packing a liner to the polymerized denture base.\textsuperscript{3,19} Conversely, Kawano et al reported that there is a significant increase in bond strength when the soft liner is processed alongside polymerized acrylic resin.\textsuperscript{20}

It is imperative to create a reliable bond between the soft liner and the denture base for optimal function. As a result, attempts to improve bonding and achieve a longer and more cost-effective durability of these materials are essential.\textsuperscript{1,2} The aim of the present study was to compare the bond strength of three permanent silicone (Molloplast-B, PermaFlex) and acrylic resin (AcroSoft) soft liners to the denture base with both synchronous and asynchronous processes and various surface treatments after thermocycling. The null hypotheses were that surface treatment would not have any effect and that synchronous processing would result in better bonding between the soft liner and the acrylic resin.

**MATERIALS AND METHODS**

In the current study, the tensile bond strength of three types of soft liners was investigated: Molloplast-B, Detax, batch no: 030522 (Group M); PermaFlex, Kohler, batch no: 08034 (Group P); and AcroSoft, Marlic, batch no: 012987 (Group A). The bonding to an acrylic resin in denture base (Ivocap, Ivoclar Vivadent, batch no: 10630275) was measured.

Six overall groups were studied: one synchronous processing, one asynchronous processing, and four groups with different surface treatments. Each group was divided into three subgroups based on the soft liner type so that there were 18 groups in total (Fig 1). Based on Jagger et al,\textsuperscript{16} with 95% accuracy and a power of 80% for each group, the sample size was calculated as 11 per group, and there were 198 samples in total.
Asynchronous Soft-Liner Processing

First, templates were produced using a three-dimensional (3D) printer (Atom) and prepared in a cylindrical shape with a diameter of 7 mm (Fig 2). This template was then replaced with PMMA during the laboratory putty flasking procedure. According to the manufacturer’s instructions, the PMMA was processed for 7 hours at 72°C.

The acrylic resin surfaces were then prepared as follows:

- **Control group**: No preparation.
- **Phosphoric acid (36%) group**: Samples were etched for 30 seconds, washed for 30 seconds, and then dried for 20 seconds.
- **Er:YAG laser group**: Pulse energy of 200 mJ and 10 Hz for 10 seconds was employed. The distance of the probe tip from the specimens was 10 mm, and the spot size was 0.8 mm. Water cooling was also utilized.
- **Grit-blasting group**: 150-μm aluminum oxide particles for 10 seconds at a pressure of 0.2 MPa at a distance of 10 mm with an airborne particle-abrasion instrument (Dentalfarm).
- **Monomer group**: Immersion in methyl methacrylate monomer (Ivocap, Ivoclar Vivadent) for 180 seconds was employed. After immersion, the samples were dried.

After treatment, the specimen's surface was inspected using scanning electron microscopy (SEM) (EVO LS10, Zeiss). The surface

**Fig 1** Study design. Group M = Molloplast-B; Group P = PermaFlex; Group A = AcroSoft.

**Fig 2** (a) Template for making acrylic resin samples. (b) Template in putty flasking.
RESULTS

The processing method (synchronous [S] or asynchronous [Control]) affected the bond strength as follows: Group M (1.9 ± 0.2 MPa [S], 2.5 ± 0.34 MPa [Control]; \( P = .71 \)); Group P (0.8 ± 0.1 MPa [S], 1.2 ± 0.1 MPa [Control]; \( P = .22 \)); Group A (14.7 ± 2.1 MPa [S], 7.0 ± 1.2 MPa [Control]; \( P < .001 \)) (Fig 4).

In addition, the different methods of PMMA surface treatment in Group M determined that the monomer method had a higher bond strength than the control.

topography generated in each type of preparation was evaluated.

A recommended thickness for a soft liner is 3 mm, so after surface treatment and creation of a 3-mm space, a soft liner was packed between two acrylic resin samples and processed according to the manufacturer’s instructions (Fig 3). The processing instructions for Molloplast-B and PermaFlex are 100°C for 2 hours, and for AcroSoft, 30 minutes at 100°C.

**Synchronous Soft-Liner Processing**

In this method, a mold was made using a template. The spacer template was then laid in the middle of the specimen space. PMMA dough was packed, flaming was performed, and a 15-minute bench cure was allowed. Then, the flask was opened and the spacer template removed. The soft liner was packed in the space, and acrylic resin processing was carried out according to the manufacturer’s instructions (7 hours at 72°C).

The number of samples for each type of soft liner was 66, and for each group, the number of samples for surface treatment was 11 (Fig 1).

After the samples were cooled at room temperature for 20 minutes, they were thermocycled (Nemo) between 5°C and 55°C for 5,000 cycles, equivalent to 1 year of use. The duration of each cycle was 1 minute. After thermocycling, the samples were stored in distilled water at 37°C for 1 week. A tensile strength test was performed with a universal testing machine (Santam) at a speed of 5 mm/minute.

Tensile bond strength was calculated using the formula \( S = F/D \), in which \( F \) (N) is the amount of force necessary to cause failure, \( D \) (mm²) is the dimension of the sample cross-section, and \( S \) (MPa) is the stress required per unit area to cause a rupture in the specimen.

After the tensile test, the specimens were examined by the naked eye for adhesive (bonding surface), cohesive (soft liner), or mixed (bonding surface and soft liner) separation failure. The results were described in statistical tables and charts. For analysis, Dunn and Kruskal-Wallis tests were used. The significance level of the tests was 5%, and the software used was SPSS 11.5 (IBM).

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**Table 1** Mean (± Standard Deviation) Values of Tensile Bond Strength (MPa) for Each Group

<table>
<thead>
<tr>
<th>Surface treatment</th>
<th>Group M</th>
<th>Group P</th>
<th>Group A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asynchronous processing (control)</td>
<td>2.5 (± 0.3)</td>
<td>1.2 (± 0.1)</td>
<td>7.0 (± 1.2)</td>
</tr>
<tr>
<td>Acid etch</td>
<td>1.2 (± 0.7)</td>
<td>1.1 (± 0.2)</td>
<td>7.9 (± 1.0)</td>
</tr>
<tr>
<td>Er: YAG laser</td>
<td>1.9 (± 0.2)</td>
<td>0.8 (± 0.2)</td>
<td>6.0 (± 1.1)</td>
</tr>
<tr>
<td>Grit blasting</td>
<td>0.7 (± 0.2)</td>
<td>0.5 (± 0.2)</td>
<td>4.8 (± 0.7)</td>
</tr>
<tr>
<td>Monomer application</td>
<td>3.1 (± 0.5)</td>
<td>2.1 (± 0.3)</td>
<td>8.1 (± 0.8)</td>
</tr>
<tr>
<td>Synchronous processing</td>
<td>1.9 (± 0.2)</td>
<td>0.8 (± 0.1)</td>
<td>14.7 (± 2.1)</td>
</tr>
</tbody>
</table>

**Fig 3** (a) Spacer template (3 mm). (b) Flanking of PMMA with spacer template. (c) Removal of spacer template, leaving space created for the soft liner.

**Fig 4** Mean tensile bond strengths for synchronous and asynchronous processing.
group ($P = 1.00$), and the other surface treatment methods produced a lower bond than the control group. Grit-blasting and acid etching had the lowest bond strength ($P < .001$).

Furthermore, in the different PMMA surface treatment methods for the Group P soft liner, it was found that grit-blasting had the lowest bond strength ($P < .001$). Monomer reported the highest bond strength; however, it was not significant compared to the control group ($P = .60$).

In the Group A soft liner, the grit-blasting method also resulted in a significantly lower bond strength than that of the control method ($P < .001$); however, there was no significant difference compared to the other methods.

In the synchronous samples, the bond strength for the Group A soft liner was significantly higher than that of the other two soft liners ($P < .001$) (Table 1).

In addition, different types of detachment or tear in a variety of processing methods and surface treatments were observed. In the Group M ($n = 66$) subgroups for asynchronous processing ($n = 55$), 27 samples demonstrated adhesive failure and 28 mixed failure, while in the synchronous subgroup ($n = 11$), 7 samples showed adhesive failure and 4 showed mixed failure. In the Group P ($n = 66$) subgroups for asynchronous processing ($n = 55$), 40 samples showed adhesive failure and 15 showed mixed failure, while in the synchronous subgroup ($n = 11$), 9 samples showed adhesive failure and 2 showed mixed failure. For the Group A ($n = 66$) subgroups for asynchronous processing ($n = 55$), there were 28 adhesive failures, 23 mixed failures, and 4 cohesive failures. In the synchronous subgroup, all failures ($n = 11$) were cohesive. The SEM evaluation of PMMA after surface treatment showed irregularities, shallow and deep cavities and porosities, and depressions with sharp and coarse angles (Fig 5).

**DISCUSSION**

As presented in the results, Group A had the highest bond strength, and the synchronous processing was significantly effective just for this group. Among the surface treatment methods, the monomer application had a better bond than the control group.

Consequently, the null hypothesis was rejected. The present study found that the application of monomer on acrylic resin for 180 seconds before application of the soft liner is an effective way to increase the bond strength. In the case of Groups M and P, the best results were produced by the monomer group, and these were significant in comparison with other types of surface preparation ($P < .001$). Also, mixed failures were more common. In Group A, synchronous processing and monomer preparation showed the highest bond strength.

**Fig 5** SEM images of surface treatments. (a) Grit blasting. (b) Laser. (c) Monomer application. (d) Phosphoric acid application. (e) Control.
Cavalcanti et al demonstrated that acrylic resin surface preparation with monomer for 180 seconds before applying the soft liner significantly increased the bond strength. The SEM analysis of the preparation with the monomer showed that the acrylic resin surfaces were cleaner and softer than the control groups and that the monomer created a depolymerized surface that strengthened the bond. Sarac et al and Kulkarni and Parkhedkar also confirmed the results of the present study. The best common method for increasing the bond strength of acrylic resin to soft silicone liners is to prepare the acrylic resin for 180 seconds with the monomer.

The present study showed that the acrylic resin and silicone soft liner synchronous processing method produced an inferior bond to that of the control group, but that the differences were not significant ($P = .993$ for Group M and $P = .112$ for Group P). The synchronous method employed by Kawano et al for Molloplast-B reduced the bond strength more than the conventional processing method, results that are consistent with the present study on Groups M and P.

In research by Jagger et al, the bonding strength of the synchronous method was greater than the conventional methods for Molloplast-B. In this study, the acrylic samples were allowed to be bench cured for 18 hours under pressure before applying the soft liner. This waiting time before packing the liner provided conditions for effectively condensing the soft liner against the acrylic resin. In fact, the high viscosity of the soft liner can displace the acrylic dough and so does not allow for proper integrating; therefore, if acrylic resin is allowed to be bench-cured for a longer period, a better and more effective pressure can be applied to create the bonding and interlocking. The synchronous processing method in Group A was found to be the most effective method for improving the bond. In fact, because the chemical composition of the soft liner and acrylic resin samples are the same, the synchronous processing provides better chemical bonding between these two materials. In Group A, all bonding failures were cohesive.

The present study demonstrates that preparation of acrylic resin surfaces using an Er:YAG laser at 200-mJ pulse energy and 10-Hz pulse frequency for 10 seconds before applying the soft liner to acrylic resin samples does not produce better results than the control group. The laser in the Group A soft liner resulted in a significantly lower bond strength than the synchronous processing groups ($P < .001$). SEM photographs show clear, distinct, and deep cavities. It was expected that these cavities and depressions would provide better mechanical adhesion; however, the results did not confirm this suggestion, possibly because of the acrylic resin surface melting caused by the heat generated during laser application and by the chemical changes, higher stress, and adhesive surface damage.

Consistent with the results of the present investigation, Gundogdu et al reported that the laser group had poorer results than the control group for Molloplast-B. The results of both studies, however, were not significant. Jacobsen et al employed a CO$_2$ laser for Molloplast-B, which significantly reduced the bond strength.

The study by Akin showed that acrylic resin surface preparation with the Er:YAG laser increased the bond strength of acrylic resin to the PermaFlex soft liner. KTP and Nd:YAG lasers were ineffective in improving the bond strength of the soft liner to acrylic resin. An increase in the bond strength of the soft liner to acrylic resin was observed in the study by Korkmaz. The increase in porosity and the clamping mechanism, due to cavities being created by laser irradiation in the acrylic resin surface, heightens the bond strength of the soft liner to the acrylic resin.

In the Akin et al study, after preparation with the Er:YAG laser, light-activated acrylic resin had a better bond strength to the Molloplast-B soft liner than did the control group. In the Usumez et al study, surface preparation with the Nd:YAG laser raised the bond strength of the Molloplast-B soft liner to the Paladent acrylic resin samples. This increase, however, was not significant. Lasers of various energy levels, numerous types of acrylic resin with different energy absorption capacities, and thermocycling are the fundamental differences affecting the results. Due to these factors and their conflicting results, further studies are needed in this field.

In Group M, the bond strength in the acid-etching group was significantly lower than that of the control and monomer groups ($P < .001$). Other types of surface preparation were not significant in comparison. Also, in Group P, the bond strength after acid etching was significantly lower than in the monomer group ($P < .001$); but was significantly higher than in the grit-blasting group ($P < .001$). According to the study by Gundogdu et al, surface treatment with 36% phosphoric acid increased bond strength, but this was not significant. A group soft-liner surface preparation with phosphoric acid significantly increased bond strength when compared with the grit-blasting group ($P < .001$). SEM images show porosities in the acid treatment surface, but in this investigation, these porosities were not efficient in helping the bond of the soft liner to acrylic resin.

It was found that preparing acrylic samples by grit-blasting with 150-µm alumina particles in the asynchronous processing method produced the weakest results for all three types of soft liners. SEM images revealed that abrasion creates a polished surface, which does not provide adequate undercuts or porosities for mechanical locking. Many previous studies have shown the same results. For example, in a comparison of Molloplast-B and Ufigel P conducted by Gundogdu et
al, bond strength was reduced after airborne-particle abrasion.10 Similarly, the results of a study by Korkmaz et al also confirmed this result,13 while Jacobsen et al also reported that airborne-particle abrasion with 250-µm alumina reduced the peel bond strength of the silicone soft liner to acrylic resin.9 In a study by Akin et al, for the PermaFlex soft liner, sandblasting reduced bond strength when compared with the control group.11 When comparing Supersoft liners and Molloplast-B, Kulkarni and Parkhedkar found that the sandblasting group had a lower bond strength than the control and monomer groups.12 Usuzem et al found that acrylic resin in surface preparation with 250-µm alumina particles increased the bond strength. This difference may be attributed to the acrylic resin type, particle size, and pressure of alumina abrasion. In addition, thermocycling could also be effective.14

Immersion of samples in water and thermocycling results in water absorption and dimensional changes of the soft liner and acrylic resin. When the soft liner absorbs water, it swells. Inflation of the soft liner causes stress on the surface between the soft liner and the acrylic resin. Water absorption also changes the viscoelastic properties of the soft liner. As a result, the soft liner becomes rigid and transfers forces to the soft liner–PMMA contact area. Therefore, thermocycling is likely to reduce the bond strength of the soft liner to acrylic resin.22

Most studies showed reduced bond strength after thermocycling and the aging process,6,7,23,24 except in the Maeda et al study, in which the bond strength of Molloplast-B increased after 1,250 and 2,500 cycles, but reduced after 5,000 cycles.25 In the present study, thermocycling was performed for all samples to achieve conditions as realistic as possible.

The limitations of the present study are the lack of clinical evaluation and an incomplete reconstruction of oral conditions. There is a need for a clinical study and further research on acidic surface treatments.

CONCLUSIONS

An acrylic resin soft liner showed significantly better bond strength in comparison with two silicone soft liners. Synchronous processing significantly improved the bond strength for the acrylic soft liner, but was not effective for silicone soft liners. For all types of soft liners, surface treatment with the monomer showed better bond strength than the other surface preparations.

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