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Methods of enhancing resilient liners' adhesion to denture base resin: A systematic review

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Aim: Various methods were developed to enhance the bond between denture base and liners, for instance: mechanical (laser, sandblasting, sandpapering) and chemical (monomer, acid etching, plasma). This systematic review studies the methods of surface treatment used in literature and their effect on soft liner adhesion and registered on INPLASY : INPLASY2024120042.

Materials and methods: Online search was performed in PubMed, EBSCOhost and Research Gate databases for free articles published between January 2010 and January 2025 to determine the studies concerning the subject. Further manual search was performed for studies mentioned in the reference list of the selected articles, in addition to articles discussed in literature reviews.

Results: A total of 102 articles were found by the online search in addition to 20 articles obtained from the manual search. Only 49 articles were included in this review by following the inclusion criteria. This review revealed that twelve of 13 articles proved the effectiveness of laser in improving bonding strength, 10 articles showed that plasma caused a rise in bonding strength, 15 articles advocated that chemicals like monomer, primers and acids can increase the strength of adhesion, while one article claimed that silica coating followed by silanization did not improve the bond. Fourteen of 19 studies showed an improvement in bonding strength following sandblasting. Nine of 12 articles revealed the reduction in bonding strength following thermocycling.

Conclusion: Laser, plasma, monomers, primers, acid etching and sometimes sandblasting are considered successful methods for enhancing the bond of soft liners, while thermocycling deteriorate it.

Keywords: soft liner, bond strength, surface treatment, laser, plasma

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Introduction

The low cost and non-invasive treatment procedures of the polymethyl methacrylate (PMMA) movable dentures have contributed to their widespread usage. Yet, wearing removable dentures is usually associated with the loss of jaw bone due to extensive pressure, resulting in a loose prosthesis.[1] Removable denture retention has a vital role in assessing how long the denture can serve; however, age-related resorption of alveolar bone can occur. It can cause an ill-fitting prosthesis, leading to pain and discomfort for the patient.[2] In an attempt to improve the fit of the denture base to the underlying supporting structures, relining the denture base can be used. It is a routine clinical procedure that helps extend the service life of the prosthesis, considering its simplicity and low cost in comparison to fabricating a new denture. It can also aid in improving patient comfort and ability to chew.[3] Soft liners are materials that are applied to the tissue surface of the denture, allowing injured tissues to recover, thus relieving pain and discomfort.[4] In addition, they assist in equally distributing the occlusal loads, thus transferring fewer stresses to the supporting tissues.[5] They may be beneficial in cases of bruxism, delicate mucosa, undercuts and after surgeries.[6]

Denture relining materials can be temporary or long-term, and auto- or heat-polymerized. Based on their chemical composition, five types of soft liners are available: chemical or heat-polymerized acrylic resins, vinyl resins, polyurethane, polyphosphazene, and heat-cured or room-temperature-vulcanized silicone rubbers.[7] Despite their numerous benefits, soft liners have some drawbacks, such as gradual loss of softness, porosity and low tearing strength that subsequently lead to bonding failure with denture base.[8] Dentures fabricated from two distinctive materials have their success related to the strength of the interface between them. The scanty bonding qualities of relining materials lead to improper adaptation and subsequently reliner delamination that induces microbial contamination of the prosthesis and prohibits proper denture hygiene.[9]

Two types of bonding can be identified depending on the chemical content of the materials, which are chemical and mechanical bond.[10] The similarity in chemical structure between denture bases and acrylic soft liners eliminates the need for adhesives or primers, and the bond is chemical. However, silicone soft liners involve a different composition that makes using adhesive essential, and the liner bonds mechanically to the denture base. In such a case, debonding is thought to be more commonly expected.[11] Researcher reported that a (0.44 MPa) bond strength and (2-3mm) thickness of liner are clinically enough for the relined denture to work properly.[12] Three generally accepted methodologies are adopted to measure the bond strength between denture base resin and soft lining material: peel, shear and tensile bond strength tests. The tensile test is preferred by the American Society for Testing and Materials (ASTM)[13]; however, Al-Athel and Jagger[14] stated that the shear test is better at simulating the liner function inside the oral cavity.

Scientists suggested various approaches to roughen the acrylic surface through mechanical and chemical methods in an attempt to enhance bonding strength, even though the effectiveness of surface roughening is still questionable. For example, Craig et al[15] supported the idea of surface roughening to improve adhesive bond, while Amin et al[16] stated that pretreating the acrylic surface with sandblasting prior to applying soft liner had weakened the bond. Furthermore, laser-treated denture bases had a lower bonding strength to relining materials, as stated by Jacobsen.[17]

This systematic review aims to evaluate the efficiency of numerous denture base surface treatment techniques in improving the liner bonding strength to denture bases, such as abrasion with airborne particles, laser treatment, chemical pretreatments, plasma and thermocycling. This review intends to give the clinicians a thorough understanding of the various ways of enhancing adhesive strength between liners and denture bases, allowing them to choose the most appropriate method of surface modification.

Materials and methods

This review study was performed following the preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and registered on INPLASY database: INPLASY2024120042. In order to determine which study is qualified to be included in this review, a thorough searching plan was established. The search included three databases: PubMed, EBSCOhost and Research Gate. The keywords "soft liner bond strength" were used. This systematic review was performed to answer the following research question: (Does the surface modification of denture base material affect the bonding strength with soft liner?). Additional manual search was conducted using the references list of the selected articles in addition to studies mentioned in review articles to check for possible inclusions. Articles were included or excluded according to criteria listed in Table 1 after reading their title and abstract. If they were unable to provide sufficient details, the full text article was reviewed. The included articles varied in terms of methodology, type of materials used, type of surface treatment and the testing methods, therefore it was not possible to perform a meta-analysis and the studies were analyzed and described in a qualitative manner.

The quality assessment and the risk of bias were analyzed by the modified Consolidated Standards of Reporting Trials (CONSORT). It consists of seven items and parameters (Sample Size Calculation, Sample Randomization, Control Group, Stating Clear Testing Method, Statistical Analyses Carried Out, Reliable Analytical Methods). A "yes" or "no" were used according to the presence or absence of each item. The number of "yes" answers were calculated for each article and the risk of bias were classified according to the following: 1–3, high; 4–5, medium; 6–7, low risk of bias. The included studies in this systematic review ranged from low to medium risk of bias. The articles with high risk of bias were not included.

Table 1: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Articles published between January 2010 and January 2025.	Articles published before January 2010.
Articles with available full text.	Articles with no full text available.
Articles in English language.	Articles in languages other than English language.
Articles studying peel, shear and tensile bond strength of silicone- or acrylic based auto- or heat-polymerized soft liners to auto-, heat-, light polymerized PMMA, polyamide, milled and 3d-printed denture base material.	Articles studying other properties of soft liners or using reinforced or hard liners.
Articles concerning with the effect of mechanical ,chemical treatment or thermocycling of denture base material on bond strength.	Articles studying the effect of antimicrobial agents, beverages or denture cleansers on bond strength.
In vitro studies.	Case reports, systematic reviews and meta-analysis.

Results

The searching process is summarized in Figure 1. The database search yielded a total of 102 articles (28 articles in PubMed, 25 in EBSCO and 49 in Research Gate) after searching with the keywords (soft liner bond strength) for free articles published between January 2010 and January 2025. Another 20 articles were obtained from the manual search for studies mentioned in systematic reviews and in the reference list of the selected articles. After excluding duplicated papers, 69 studies were checked for inclusion criteria and 20 studies were eliminated according to the reasons mentioned in Table 2. In two of the included articles, the authors used hard liners in addition to soft ones, which is considered an exclusion criteria according to this review; therefore, only the results of soft liner groups will be discussed. The final number of included studies was

49 and are discussed in this review. In the 49 included studies, 27 types of denture base materials (2 auto-polymerized, 1 light-polymerized, 20 heat-polymerized, 3 milled and one 3d printed denture base materials) and 22 types of soft liners (12 silicone-based and 10 acrylic-based) were used (Tables 3 and 4 respectively). All studies evaluated bond strength by using Universal Testing machine, albeit with varying cross-head speeds (3 articles used 20 mm/min, 8 articles used 10 mm/min, 22 articles used 5 mm/min, 1 article used 2 mm/min, 5 articles used 1 mm/min,6 articles used 0.5 mm/min, while 4 articles did not mention the used speed).

Most of the studies assessed the tensile bond strength (38 articles), while only 9 articles tested shear bond strength and 3 articles tested peel bond strength. Considering tensile and shear tests, the following equation was employed:

Bond strength N/mm = Maximum load (N)/cross sectional area (mm^2)

While for peel bond strength, the formula below was applied:

$$PS = \frac{F}{W}\left(\frac{1+\lambda}{2}+1\right)$$

where F is the maximum force recorded (N), W is the width of the specimens (mm), and λ is the extension ratio of the liner (the ratio of the stretched to the unstretched length). Supplemental Tables 1-5 summarize the included articles that investigate the change in bonding strength after treatment with laser, plasma, sandblasting, chemicals and thermocycling, respectively.

Generally, the majority of studies included in this review concluded that treating the PMMA surface with laser, plasma, primer, acids, and monomer application enhanced the adhesion between acrylic denture base and soft liner. Whereas thermocycling resulted in a decline in adhesive strength of the liner. Regarding sandblasting, its effect on liner adhesion was controversial, while some studies suggested that sandblasting can improve liner bonding, others confirmed that it has a deteriorating effect.

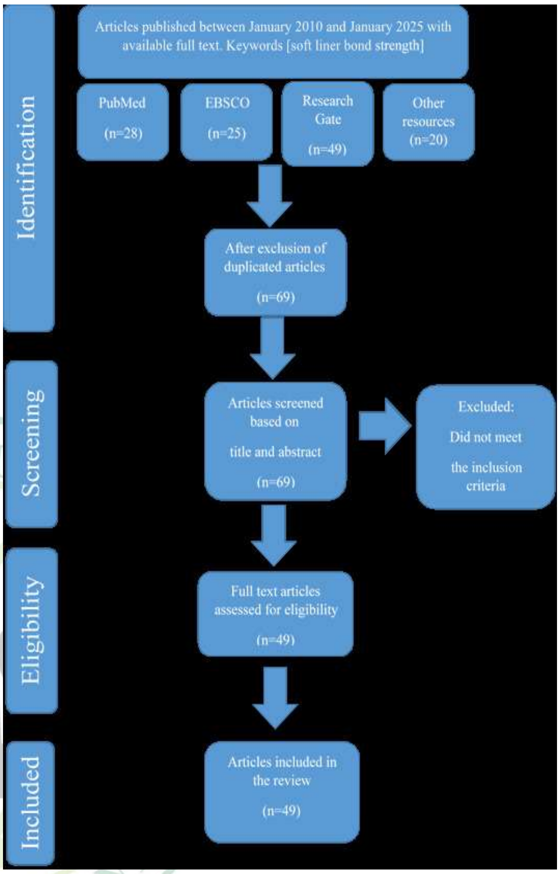

Figure 1: PRISMA flow chart of the selection process

Table 2: Reasons of exclusion

Reasons of exclusion	Number of excluded articles
Not using soft liner	4
Not performing acrylic surface treatment	12
Not providing enough information	2
Using other types of denture base material	1
No control group	1

Table 3: Types of denture base resin used

No.	Name of denture base resin	Mode of polymerization	Composition	Manufacturer
1.	Vertex Rapid Simplified (VRS)	Heat-polymerized	PMMA	VertexTM, Zeist, Netherlands
2.	Vertex Self-Curing (VSC)	Auto-polymerized	PMMA	VertexTM, Zeist, Netherlands
3.	DPI heat cure	Heat-polymerized	PMMA	Dental Products of India Ltd
4.	Meliodent	Heat-polymerized	PMMA	Bayer Dental
5.	Paladent	Heat-polymerized	PMMA	Heraeus Kulzer, Hanau, Germany
6.	Triplex	Heat-polymerized	PMMA	Ivoclar Vivadent, Schaan, Liechtenstein
7.	Superacryl plus	Heat-polymerized	PMMA	SpofaDental
8.	Implacryl	Heat-polymerized	high impact PMMA	Vertex
9.	Acron Duo	Heat-polymerized	PMMA	associated Dental Products Ltd., Kemdent, Wiltshire, UK
10.	QC-20	Heat-polymerized	PMMA	Dentsply International INC, New York, EUA
11.	Deflex	Heat-polymerized	Polyamide based	Nuxen SRL, Buenos Aires, Argentina
12.	Rodex	Heat-polymerized	PMMA improved with cross-linking	Rodont, Srl Milan, Italy
13.	Trevalon	Heat-polymerized	PMMA	Dentsply,USA
14.	Acralyn-H	Heat-polymerized	PMMA	Asian acrylates India
15.	Eclipse	Light-polymerized	UDMA	Dentsply Trubyte, York, USA
16.	Acron Duo	Heat-polymerized	PMMA	Kemdent, UK
17.	Pyrax	Heat-polymerized	PMMA	Pyrax Polymars
18.	Zi Ran	Heat-polymerized	PMMA	Nissin, Kunshan, China
19.	Ivocap	Heat-polymerized	PMMA	Ivoclar Vivadent, Schaan, Liechtenstein,
20.	Ashvin	Heat-polymerized	PMMA	Ashvin,India
21.	Denture base resin	Heat-polymerized	PMMA	Dura Dent, Erk Dental, Izmir, Turkey
22.	Major. Base 20	Heat-polymerized	PMMA	Major,Moncalieri, Italy
23.	Palapress	Auto-polymerized	PMMA	Haraeus Kulzer, Hanau, Germany
24.	NextDent Denture3D+	3D printed	PMMA	NextDent, Soesterberg, Netherlands
25.	XT-Cera	Milled denture base	PMMA	China
26.	Smile CAM total prosthesis	Milled denture base	PMMA	Pressing Dental, San Marino
27.	Opera System	Milled denture base	PMMA	Principauté de Monaco, Monaco

Table 4: Types of soft liners used

No.	Name of soft liner	Mode of polymerization	Composition	Manufacturer
1.	Ufi Gel SC (UGS)	Auto-polymerized	Silicone-based	VOCO GmbH
2.	Silagum-Comfort (SLC)	Auto-polymerized	Silicone-based	DMG Dental
3.	Mucopren Soft	Auto-polymerized	Silicone-based	Kettenbach GmbH Eschenburg Germany
4.	Molloplast-B	Heat-polymerized	Silicone-based	Detax GmbH & Co. KG
5.	Luci-Sof	Heat-polymerized	Silicone-based	Dentsply, International Inc.,Usa
6.	Mollosil	Auto-polymerized	Silicone-based	Detax
7.	Permaflex	Heat-polymerized	Silicone-based	Kohler, Neuhausen, Germany
8.	GC Reline soft	Auto-polymerized	Silicone-based	GC Corp., Tokyo, Japan
9.	Softliner	Auto-polymerized	Silicone-based	Promedica/ Germany
10.	Elite soft	Auto-polymerized	Silicone-based	zhermack
11.	Sofreliner Tough M (ST)	Auto-polymerized	Silicone-based	Tokuyama Dental Corp., Tokyo, Japan
12.	Dinabase	Auto-polymerized	Silicone-based	Italy
13.	Vertex Soft (VTS)	Heat-polymerized	Acrylic resin-based	Vertex-Dental B.V.
14.	Permasoft	Heat-polymerized	Acrylic resin-based	DENTSPLY GmbH, Germany.
15.	GC soft liner	Auto-polymerized	Acrylic resin-based	GC Corp., Tokyo, Japan
16.	Coe-soft	Auto-polymerized	Acrylic resin-based	Coe Laboratories Inc, Chicago, EUA.
17.	Acrasoft	Heat-polymerized	Acrylic resin-based	Henry Schein, USA
18.	Super-soft	Heat-polymerized	Acrylic resin-based	G.C. America Inc., USA
19.	Visible light cure reline material	Light-polymerized	Acrylic resin-based	Motloid Co., Chicago, USA
20.	Acropars	Auto-polymerized	Acrylic resin-based	Marlic Co. Iran
21.	Soft Reverse	Heat-polymerized	Acrylic resin-based	Nissin, Kyoto, Japan
22.	Dura Rely-A-Soft	Auto-polymerized	Acrylic resin-based	Dura Dent.USA

Discussion

Various types of lasers have been used in several studies in an attempt to provide a better bond of adhesion between the denture relining material and the denture base. This review has found that laser impact varies according to the type of laser, its power and the type of denture base material and liner. Additionally, it varies according to the test performed, whether it is a tensile, shear or peel bond strength test. Akin et al[18] reported that treating the surface of UDMA denture base material with an Er:YAG laser with a frequency of 10 Hz, energy of 300 mJ, power of 3 W, and pulse duration of 700 µs for 20 s is an effective way to increase the tensile bond strength of silicone-based soft liner. It is suggested that the Er:YAG laser created tiny pits and imperfections on the acrylic surface in which the soft lining material can easily penetrate, thus improving the bond. However, increasing the laser power to 4W and 400mJ resulted in damage to the adhesive surface by producing large cavities rather than pits. The same effective parameters used by Akin et al[18] were also used by Kumari et al [19] but for 3 different pulse durations (10, 20 and 30 s), and they reported a significant increase in tensile bond strength in all study groups, especially with the (30 s) pulse duration, where the tensile strength increased from (1.020 MPa) for the control group to (1.400 MPa). Gorler et al[20] advocated that irradiating the PMMA surface with an Er:YAG laser caused a significant increase in tensile bond strength with silicone based soft liner. The applied parameters were: pulse energy of 0.2J, 20Hz, 4W output power, and 2940nm wavelength. Laser energy was applied for 20 sec. They also investigated the effect of Nd:YAG and Ho:YAG lasers and concluded that both types of lasers had a lowering effect on tensile bond strength in comparison to samples that were not subjected to laser irradiation.

Moreover, Yildirim et al[21] and Nakhaei et al[22] have also proved the effectiveness of lasing denture base material with Er:YAG laser in enhancing tensile bonding strength to silicone-based denture reliner after using the same parameters as given by Akin et al.[18] Similar results were obtained by Shaikh et al.[23] Al-Shakaki and Al-Essa [24] modified the PMMA resin surface with three different powers of the Er:YAG laser (100, 200 and 300 mJ) at a pulse frequency of 10 Hz. The greatest mean value of tensile strength was recorded in the study group of 300 mj, while the control group had the lowest values. This indicates that treating acrylic surface with Er:YAG is an effective approach for strengthening liner adhesive efficiency. Comparable findings were also observed by Brahmandabheri et al.[25] Contrary results were obtained by Haghi et al[26], as they stated that Er:YAG laser was unable to improve the tensile bonding strength of the soft liner with the treated samples.

Another type of laser has been used by Aziz [27]to treat acrylic surface which is the CO2 laser. She observed a significant raise in shear bond strength in lased acrylic samples when compared to untreated ones. Korkmaz et al[28] modified the surface of three different types of denture base material (Paladent, Rodex and Deflex) with an Er,Cr:YSGG laser in two different powers and frequencies (2,3 W and 20,30 Hz). They discovered the great influence of the testing procedures and materials on the values obtained from the peel bond strength test. In the Paladent groups, the greatest level of peel bonding strength (4.74 ± 0.74) was for the group with a 3 W and 20 Hz) laser. While for the Rodex denture base material, the group of (3W and 30 Hz) laser showed the highest values (4.81± 1.32 MPa). Regarding Deflex, which is thermoplastic injectable denture base material, it showed a higher peel bond strength at the group with (2 W and 20 Hz) than other groups. The SEM evaluation of the samples' surfaces after laser treatment showed that the Er,Cr:YSGG laser with parameters (3 W-20 Hz) had the greatest impact on the PMMA morphology, where it formed a uniform distribution of microporosities. While SEM examination of Deflex specimens showed a more irregular distribution of smaller holes on the surface. The same type of laser was utilized by Ramakrishnan et al [29] and proved its effectiveness in increasing the shear bonding strength of silicone-based soft liners at 3W power and 10 Hz frequency. Alabady and Khalaf [30] proved the effectiveness of the Nd:YAG laser in enhancing the tensile bonding strength of an acrylic-based soft liner to thermoplastic denture base material.

Plasma treatment was found to be extremely effective in enhancing wettability of denture base materials, hence increasing bonding to soft liners. Qanber and Hamad[31] used plasma with a combination of oxygen and argon gases in a ratio of 1:1 to modify the surface of conventional and high-impact heat-polymerized denture base resins. They observed a significant rise in shear strength of acrylic-based soft liner to both conventional and high-impact specimens treated with plasma. Similar results were obtained by Zhang et al[32] who used oxygen plasma to treat denture base resin before performing tensile bond strength, and the outcomes revealed an improvement in adhesion strength from 2.8 MPa for the control group to (5.2 MPa) for the 1-day exposure group and (4.1 MPa) for the 2-day exposure group. The possible explanation for this is that oxygen gas in plasma chemically removes surface particles and thus promotes an etching process. Furthermore, new groups containing oxygen, such as O-H, C-O, and C=O, are formed on the surface of the material that improve its hydrophilic nature, hence permitting the flow of soft liner material into the deep irregularities, which in turn increases the bond.

Soygun et al[33] studied the effect of argon and oxygen plasma with three different exposure times (30, 60 and 120 s) on the tensile bond strength of a silicone-based soft liner to a heat-polymerized acrylic denture base. The authors came to a conclusion that oxygen plasma was highly effective in enhancing bonding strength, and the highest mean (2.570 MPa) was obtained from the group that was treated with oxygen plasma at an exposure time of 120 s. Yet, argon plasma showed a decline in tensile bond strength values, contrasted with the results obtained by Yildirim et al[21] and Yildirim et al[34] who reported an increase in tensile strength following argon plasma treatment for 1 minute from (0.807 MPa) for untreated specimens to (1.149 MPa)[21] and from (0.905 MPa) to (1.169 MPa) .[34] Additionally, Yildirim et al [34] have also concluded that lengthening the time of surface exposure to plasma can deteriorate the adhesive strength of liners, and shorter periods should be adopted.

The effect of oxygen and argon plasma treatment on shear bond strength of soft liner to heat- and light-polymerized denture bases was studied by Abdullah et al[35] who reported an increase in shear bond strength values of heat-polymerized denture bases treated with both oxygen and argon plasma in contrast to light-polymerized denture bases, where the effect seemed to be insignificant. Comparable outcomes achieved by Shaikh et al[23] and Xiaoqing et al[36] regarding oxygen plasma. Qanber and Hameed [37] studied the effect of plasma treatment on the bonding of acrylic-based soft liner to CAD-CAM denture base material. The results of this study showed a significant improvement of shear bond strength of denture liner after 5-minutes oxygen-argon plasma treatment of CAD-CAM acrylic material surface.

A new method of surface modification has been recently adopted to alter the denture base surface which is Thermionic Vacuum Arc (TVA). It is one of the most developing procedures for surface alteration that works in a highly vacuumed conditions. It coats the surface at a nanoscale level yielding a homogenous compact surface with a lower values of surface roughness.[38] These surfaces are more resistant to dissolving in the oral environment and they retain their properties for longer periods. Mumcu et al[38] coated the surface of heat-cured acrylic denture base material by using TVA plasma system with three different coating materials: The Zinc Oxide (ZnO), TinIVoxide (SnO2), and Silver (Ag). Evaluation of the study data showed that surface treatment of denture base material with TVA plasma using ZnO caused a significant increase in tensile bond strength (1.18 MPa) compared to control group (0.83 MPa); however, using SnO_2 and Ag negatively affected the bonding strength.

Using sandblasting as a mechanical method of roughening the surface of denture bases in order to strengthen the liner-base connection is a topic of debate. While some investigators reported an increase in liner adhesion after sandblasting, others stated that it has a weakening effect.[39] According to Khanna et al[40], the impact of sandblasting treatment is influenced by the type of liner used, whether it is an acrylic- or silicone-based resilient liner. They concluded that sandblasting the PMMA surface is effective in increasing shear bond strength of acrylic-based soft liner; however, the increase was statistically insignificant with silicone-based soft liner. This may be due to the similar chemical composition between acrylic liner and denture base material, in addition to the increased surface area of connection resulted from sandblasting. On the other hand, the little increase in shear bond strength with silicone liners can be the result of frictional forces formed when the two contacting surfaces move relative to each other. [40]

The influence of the particle size of aluminum oxide used for sandblasting on bond strength of soft liners was studied by Swapna et al[5], where they used three different particle sizes (50, 150 and 250 µm) as the sandblasting medium. The authors found that sandblasting led to a decline in the tensile bond strength values of all of the three soft liners used (auto-, heat- and light-polymerized). However, the shear bond strength was increased which may be caused by the increased force needed to overcome the friction arising from moving the two parts of the specimen. They also found that changing the particle size had no effect of bonding strength, opposing the results of Akay et al[41], who used three different particle sizes (30,50 and 110 µm) and showed that the maximum tensile bond strength was obtained from the smallest particle size (30 µm). Similarly , Kuźniarski et al[42] reported that the strength of bonding can be compromised after using too large particles (350 µm). Additionally, the study found that sandblasting could have an enhancing or weakening effect on tensile bond strength depending on the type of soft liner used. Similar results were shown by Akin et al[43], who advocated that the size of Al_2O_3 particles can affect the strength of bonding and the size of 120 µm is effective in increasing tensile bond strength while 50µm size particles lowered the tensile strength. Atsü and Keskin[44] agree with this result.

Brahmandabheri et al[25] and Dastjerdi et al[45] used 50µ Al_2O_3 particles to sandblast the acrylic surface and confirmed the efficiency of such treatment in enhancing the bond. The positive effect of sandblasting on enhancing the bonding strength was also observed by Mempally et al[46] and Nakhaei et al[22] after using 250 µm and 110 µm particle sizes respectively. Opposing results were showed by Gorler et al[20], Haghi et al[26] Korkmaz et al[28] Surapaneni et al[48] and Kulkarni and Parkhedkar[49], where they proved that sandblasting has a deteriorating effect on denture liner bond strength. Stresses formed at the liner/base junction, insufficient size of surface irregularities formed by sandblasting and the inability of soft liner to penetrate into irregularities due to its high viscosity are all possible explanations for the reduced bonding strength following sandblasting.[42] The influence of sandblasting of CAD-CAM denture base material surface on the adhesion strength with soft liners was discussed by Al Taweel et al[50] where they abraded the surface of both conventional and CAD-CAM denture base materials with 110µm alumina particles and tested for tensile bond strength. Testing results showed an improvement in tensile bond for both types of denture base materials. Similar results were obtained by Shaaban et al.[51] Gopal et al[52] investigated the effect of sandpapering with 100 grit sandpaper in addition to mechanical preparation of surface holes (Six holes with dimensions of 0.75 *1.00 mm width and height respectively drilled with a No. 14 Tungsten Carbide inverted cone bur) on bonding strength. Both procedures showed an improvement in tensile bond strength of both types of soft liners used (Super-soft and Molloplast B).

Chemical treatment of the acrylic surfaces by monomers, chemical etchant or surface coating has been widely used in literature with the intention of providing a stronger adhesion to soft relining materials. Pradeep et al[53] observed a significant increase in tensile bond strength of two types of soft liners (Molloplast B and Mollosil) to three different denture base materials (DPI, Ashwin and Trevelon) after treating the acrylic specimens with monomer combined with sandblasting treatment with 250µm aluminium oxide particles. Khanna et al[40] treated the acrylic specimens of one of their study groups with methyl methacrylate monomer for 180 s. This treatment resulted in highly increased shear bond strength for both acrylic- and silicone-based soft liners. Such an increase can be explained by the fact that the denture base monomer has the ability to polymerize; thus, it contributes to the improved bonding by penetration into the denture base and participation in the polymerization process.[40] Almuraikhi [54] studied the impact of monomer treatment of acrylic surface along with surface etching by phosphoric acid. The study showed a superior and significant rise in tensile bond values from 0.94 MPa for untreated samples to 1.88 MPa and 1.16 MPa after monomer application and phosphoric acid etching, respectively. Comparable outcomes were attained by Al-Shakaki and Al-Essa[24], Mempally et al[46] , Kulkarni and Parkhedkar[49] and Haghi et al.[26]

Some studies investigated the effect of some surface etching solutions such as chloroform, dichloromethane [55], methylene chloride [56] and acetone,[46,56] in addition to monomer application. Application of acetone and surface wetting by monomer can result in development of surface cracks and the creation of several 2-µm-diameter pits.[57] Upon monomer application, the PMMA resin base swells and expands, hence assisting the primer of liner's adhesive to infiltrate deep into surface cracks and pits, leading to reduced micro-leakage and enhanced bonding strength.[58] Phosphoric acid and ethyl acetate solutions were utilized in several studies in an effort to enhance the liner bonding strength to the denture base. Sabah and Khalaf [59] and Brahmandabheri et al[25] reported an increase in the bonding strength of soft liners after acrylic surface treatment with ethyl acetate and phosphoric acid, respectively. Opposing results in the study of Haghi et al[26] showed the ineffectiveness of phosphoric acid at improving liner bonding.

Another procedure has been conducted in order to modify denture base resin prior to soft liner application is by coating PMMA surface with silica particles. This approach was used by Atsü and Keskin. [44] They found that there was no increase in tensile bond strength of silicone-based soft denture liner (Ufi gel P) to the heat-cured denture base resin (QC-20) after surface coating with silica and silanization following coating. This result can be explained by the fact that coating PMMA surface with 30µm silicon-dioxide particles can result in a rough and irregular surface, yet the size of these irregularities may be insufficient to permit the easy flowing of soft liner into base resin, thus reducing bonding strength.[44] Goiato et al[60] treated the surface of heat-cured acrylic resin with a primer containing solvents (99.5%) and agents of union (0.5%) in its composition. A slight increase in tensile bond strength of an acrylic-based soft liner was observed following primer application, however the increase was not statistically significant. SEM images showed a layer of union agents on the surface of the acrylic after primer application. The authors assume that the slight increase in tensile strength values and the majority of cohesive failures are related to the presence of the solvent due to its conditioning effect on the resin surface. Furthermore, the increased percentage of cohesive failures indicates a higher liner-PMMA adhesive force than the intermolecular forces of soft liner.[60] Kümbüloğlu et al[61] proved that primer application and silica coating resulted in an increase in tensile bond strength of PMMA-based soft liner to both PMMA and Polyamide denture base materials. Additionally, a significant increase in the tensile bond strength of silicone-based soft liner was observed by Ariyani et al[47] following primer application and sandblast-primer combination.

Oral environment is considered a major factor in the deterioration of the relined dentures due to the continuous thermal fluctuations and recurrent flexural stresses that lead to minimizing their clinical life.[25] A simulated oral condition can be reproduced in vitro by thermocycling, and it is of extreme importance to assess the bonding strength of soft liner under such conditions to estimate the ability of soft liner to resist debonding and intrinsic fractures during clinical service.[55] In the majority of the studies included in this review, thermocycling led to a decline in bonding strength values of the tested specimens. This result was achieved by Gorler et al[20], Brahmandabheri et al[25], Sabah and Khalaf [59], Nakhaei et al [22] , Ariyani et al [47] and Sreenivasulu and Shyammohan.[62] The types of soft liners used in these studies were silicone-based[20,22,25,47,62] and acrylic-based [59,62] soft liners and were tested for tensile bond strength except for Sabah and Khalaf[59] who performed a shear bond strength test. This decline is thought to be caused by the massive amount of water ingressed at the liner-denture base junction that leads to swelling and stress concentration at the interface, in addition to changes in viscoelastic features of the relining material.[59] In case of using acrylic-based soft liners, water uptake can indirectly decrease the bonding strength by allowing the plasticizers to leach out of the liner, increasing its stiffness and diminishing the elasticity. Consequently, this reduced elasticity leads to increased bond vulnerability due to direct transmission of loads at the interface rather than being absorbed by the elastic liner.[63]

Madan and Datta[63] and Demir et al[64] studied the relation between the influence of thermocycling on the liner bonding strength and the type of the soft liner being used. According to Madan and Datta[63], the heat-temperature vulcanized (HTV) silicone-based soft liner (Molloplast B) showed a significant decrease in tensile bonding strength following thermocycling, while room-temperature vulcanized (RTV) silicone liners exhibited enhanced bonding strength values after being thermocycled. This result contradicts the result obtained by Demir et al[64] who stated that Molloplast B was more stable during thermocycling and its peel strength remained unchanged, while Permaflex showed a decrease in its peel strength values. It is thought that the filler particles in Permaflex absorbed larger amounts of water during thermocycling than Molloplast B, which led to greater dimensional changes and subsequently shear stress concentration at the interface, thus weakening bonding strength.[64] According to Rajaganesh et al[65], thermocycling caused a slight increase in shear bond strength of silicone-based soft liner with a slight decrease in shear bond strength of acrylic-based soft liner, although these changes were statistically insignificant. A study by Goiato et al[60] revealed that thermocycling resulted in a minor yet statistically insignificant increase in the tensile bonding strength of an acrylic-based soft liner. On the other hand, Geramipanah et al[66] stated that thermocycling both acrylic- and silicone-based soft liners has no effect on their tensile bond strength; however, acrylic-based soft liner showed a change in the mode of failure after thermocycling from mixed to predominantly adhesive failure. Janyaprasert et al[67] investigated the effect of thermocycling on the adhesive strength of soft liners to four types of denture bases which are: autopolymerized, heat-polymerized, milled and 3d printed denture base materials. The results showed that there was no change in tensile bond strength of acrylic-based soft liners (GC soft liner) after thermocycling, while it changed significantly with silicone-based soft liners. Sofreliner tough M soft liner showed an increase in the tensile bond strength with all types of denture bases after thermocycling, in contrast to Ufi gel P soft liners which had a decreased adhesion strength to milled and 3d printed denture base materials.[67]

The authors couldn't find clinical studies that discuss the effect of the surface treatment of the denture base on the bonding strength with soft liners. Thus, it is considered a limitation for this study that it is based only on in vitro studies. Lack of clinical studies makes it difficult to understand the actual behavior of soft liners throughout the clinical use. During function, relined dentures are subjected to a multidirectional force with different magnitudes, while laboratory tests apply a unidirectional force, thus it cannot fully represent the actual conditions in the oral cavity. Therefore, clinical studies concerning with the bonding strength of soft liners should be conducted to support the findings obtained from in vitro studies.

Conclusion

This systematic review came out with the following conclusions:

1. Treating denture base resin with laser irradiation, plasma, monomers, primers and acid etching all are effective methods for enhancing the bonding strength of soft denture liners.
2. Sandblasting can have an enhancing or deteriorating effect on soft liner bond strength depending on the particle size and the type of the soft liner being used.
3. Thermocycling brought about a decline in bond strength of soft liners in nearly all of the included studies.

Competing interest
The authors declare no competing interest

Data availability
The data is available within the manuscript

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