Evaluation of tensile bond strength between two types of denture base resins and a resilient denture liner

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ABSTRACT

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This study aimed to evaluate the tensile bond strength between two different denture base resins with a resilient denture liner based on surface treatment and thermocycling. A rectangular plate measuring 25 mm × 25 mm × 3 mm was designed using computer-aided design software and exported as a standard tessellation language (STL) file. For the denture base resin group for 3D printing (Group TDP), the specimens were fabricated from the STL file using a 3D printer (*n* = 144). For the traditional heat-cured resin group (Group HEA), a wax specimen was milled from the same STL file and embedded in dental plaster and type III dental stone. After wax elimination, resin was injected using an injection machine, and the specimens were manufactured through deflasking (*n* = 144). All resin specimens were polished with 600-grit sandpaper and stored in distilled water at room temperature for 24 hours. A pair of resin specimens, i.e. two individual resin specimens, was required for each tensile bond strength test. Therefore, the final number of specimens used for both Groups TDP and HEA was 72 each. Subgroup N received no surface treatment, Subgroup S was sandblasted with 110 μm aluminum oxide for 10 seconds, and Subgroup B underwent light curing for 10 seconds after application of a bonding agent. The denture liner was poured and bonded using a polytetrafluoroethylene ring, after which the denture base specimen was positioned on top. The assembled specimens were stored at room temperature for 24 hours. Half of the specimens underwent 3,000 cycles of thermocycling. Tensile bond strength tests were performed at a crosshead speed of 10 mm/min using a Universal Testing Machine. Statistical analyses were conducted using statistical one-way analysis of variance (ANOVA) for surface treatments and two-way ANOVA for thermocycling and denture base resin types. A *p*-value of less than 0.05 was considered statistically significant, and post-hoc analysis was performed using the Bonferroni method. No significant differences were observed in tensile bond strength among the three surface treatment methods, irrespective of material type and thermocycling. However, in Group TDP, tensile bond strength values were significantly lower after thermocycling compared to before thermocycling, whereas no significant differences were found in Group HEA ($p = 0.016$ for TDP; $p = 0.294$ for HEA). Group TDP demonstrated significantly lower tensile bond strength than Group HEA both before and after thermocycling ($p < 0.05$). The 3D printable denture base resin exhibited a lower bond strength to the resilient denture liner after thermocycling compared to heat-cured denture base resin. Despite these observed differences, the tensile bond strengths of both denture base resins exceeded clinically acceptable thresholds for attaching the resilient denture liner.

Key words: 3D printing, additive manufacturing, resilient denture liner, tensile bond strength test, thermocycling, surface treatment, denture base resin

1. INTRODUCTION

The rehabilitation of edentulous areas using removable dentures is a fundamental treatment modality for restoring function and aesthetics in patients with partial or complete edentulism. Following multiple tooth extractions or dental implant placement, interim removable dentures (IRDs) are often employed during the healing phase to temporarily restore masticatory function and aesthetics (Smith, 1984; Swoope et al., 1974). These prostheses support daily activities and help patients acclimate to the sensation of wearing dentures before transitioning to definitive ones. Furthermore, IRDs play a protective role by mitigating complications such as excessive bleeding, alterations in facial structure, diminished oral function, and nutritional deficiencies (Winkler et al., 2005).

Traditionally, IRDs have been fabricated using heat-cured or self-cured resins. Heat-cured resins provide durability and wear resistance, while self-cured resins provide convenience and faster fabrication (Ayman, 2017; Gratton and Aquilino, 2004; Pellizzer et al., 2010). Despite their effectiveness, these conventional materials have inherent limitations. Heat-cured resins require a lengthy and complex fabrication process. Self-cured resins contain higher levels of residual monomers (Kwon et al., 2012; Pfeiffer and Rosenbauer, 2004).

Computer-aided design / computer-aided manufacturing (CAD/CAM) technology has introduced more efficient methods for fabricating removable dentures. Although CAD/CAM technology has been utilized in dentistry for decades, the first attempt at producing digitally fabricated removable dentures was reported in the 1980s (Goodacre et al., 2012). Currently, two primary methods are employed in digital denture manufacturing: milling and three-dimensional (3D) printing (additive manufacturing). In milling, dentures are fabricated by trimming pre-polymerized resin blocks; however, this method generates material waste, and the final outcomes may not fully replicate the original design due to the limitations of milling burs.

Among the American Society for Testing and Materials (ASTM) classifications of 3D printing, vat photopolymerization and material jetting are widely used in dentistry due to their compatibility with resin-based printing materials (ASTM International, 2012). 3D printing offers flexibility in material selection and is not constrained by design limitations. However, the process is time-consuming and requires post-curing (Strub et al., 2006). 3D printing fabricates objects layer by layer using a 3D design file. Compared to milling, it offers several advantages, including reduced maintenance costs, less material waste, and the ability to produce complex structures for larger prostheses (Van Noort, 2012). Additionally, the digital workflow associated with 3D printing reduces patient visits and enables easy replication of dentures through stored patient data. Studies have shown that 3D-printed dentures fabricated using digital scanning significantly shorten the overall fabrication time compared to conventional methods (Marinello and Brugger, 2021; Sanjeevan et al., 2021).

This digital approach also minimizes errors inherent in conventional denture fabrication processes, which rely heavily on the technician skills. Given the practical benefits and enhanced durability of 3D-printable materials, the adoption of 3D-printing technology is expected to optimize the removable denture fabrication processes and expand their clinical applicability (Alhallak et al., 2023; Deng et al., 2021; Lin et al., 2019; Tian et al., 2021).

Digitally fabricated removable dentures enable easy replication; therefore, if patients lose or fracture their dentures, new ones can be quickly refabricated using stored patient data (Anadioti et al., 2020; Steinmassl et al., 2018). However, for edentulous ridges that have recently undergone surgical procedures such as tooth extractions or implant placements, fully leveraging the advantages of 3D printing for fabricating removable dentures, particularly IRDs, can be challenging. This is due to rapid changes in the residual alveolar ridge during the healing period. Therefore, it is often necessary to reline IRDs with resilient denture liners or refabricate them to accommodate the altered ridge morphology, ensuring retention and stability. Refabrication, however, is typically impractical due to concerns about patient comfort and cost. Thus, relining IRDs is the most practical and widely used solution, performed either directly in the clinic or indirectly in a laboratory (Pisani et al., 2012; Shiga et al., 2007). The direct chairside method is straightforward, allowing patients to avoid time without dentures. The indirect method, which involves applying denture base material after obtaining an impression, yields stronger results with fewer air bubbles (Hill and Rubel, 2011; Yoshida et al., 2013).

Resilient denture liners are elastic materials applied to the tissue side of denture bases to cushion masticatory forces and ensure a precise fit with intraoral tissues (Maciel et al., 2019; Prosthodontics, 2023). Initially made from natural rubber in the 19th century, synthetic resin liners were introduced in 1945, followed by silicone-based liners in 1956 (El-Hadary and Drummond, 2000; Muddugangadhar et al., 2020). Today, acrylic and silicone liners are most commonly used. Acrylic liners, composed of polymers and monomers with plasticizers, soften initially but tend to harden over time, reducing patient comfort. Silicone liners, composed of biocompatible dimethyl siloxane, maintain their softness and durability; however, they do not chemically bond to heat-cured resins, posing adhesion challenges (McCabe et al., 2002).

Resilient denture liners must remain securely attached to the tissue surface of denture bases to effectively cushion and distribute masticatory forces, reduce pain, and enhance denture retention. Secure bonding also prevents the formation of environments conducive to bacterial growth, minimizing risks of inflammation and infection (Mutluay and Ruyter, 2007). Weak bonding between liners and denture bases can result in food entrapment and plaque accumulation, increasing these risks. Factors such as resin type, liner type, water immersion, aging, and surface treatments influence liner performance (Kim et al., 2014; Kreve and Dos Reis, 2019; Mutluay and Ruyter, 2007).

Recent studies have explored methods to improve the bonding strength between heat-cured resins and resilient liners using various surface treatments, such as sandblasting and the application of bonding agents. These treatments are believed to enhance both mechanical interlocking and chemical bonding between the materials (Laney, 1970). For surface treatments, it has been reported that using monomers in the heat-cured group resulted in greater tensile bond strength compared to untreated or acid-treated surfaces (Almuraikhi, 2022). Additionally, the tensile bond strength of both light-cured and heat-cured resins was shown to decrease under thermocycling conditions, which simulate the temperature fluctuations of the oral cavity (Al-Athel et al., 2002).

Despite advancements in 3D-printable denture base resin materials, limited research exists on the tensile bond strength between 3D-printed denture bases and resilient denture liners. This study aimed to evaluate the tensile bond strength between a resilient denture liner and both heat-cured and 3D-printed denture base resins. Additionally, the effects of thermocycling and surface treatments on the tensile bond strength of these combinations were evaluated. The first null hypothesis was that no significant differences would exist in the tensile bond strength of the resilient denture liner applied to heat-cured and 3D-printed denture base resins. The second null hypothesis was that neither surface treatments nor thermocycling conditions would significantly affect tensile bond strength.

2. MATERIALS AND METHODS

2.1. Preparation of Specimens

This study was conducted in compliance with International Standard Organization (ISO) 10139-2:2016 (ISO 10139-2:2016). A rectangular plate measuring 25 mm × 25 mm × 3 mm was designed using CAD software and exported as a standard tessellation language (STL) file. For the 3D-printed denture base resin group (Group TDP), a total of 144 specimens were fabricated from the STL file using a 3D printer (NextDent 5100; NextDent, Soesterberg, The Netherlands) with denture base resin material (NextDent Denture 3D+; NextDent; Figure 1). The printed specimens were cleaned with 94 % ethyl alcohol for 5 minutes and post-cured in a curing unit (LC-3Dprint Box; NextDent) for 30 minutes to complete secondary curing.

For the conventional heat-cured resin group (Group HEA), the same STL file was used to mill 144 wax specimens (α wax block; Alphadent, Gyeonggi-Do, Korea). The fabricated wax specimens were fixed onto a glass plate with type III dental stone (Snow Rock; DK Mungyo, Gyeongsangnam-do, Korea) and embedded with plaster for the upper portion. A sprue (IvoBase wax patterns; Ivoclar Vivadent AG, Schaan, Liechtenstein) was positioned on top of the wax model and covered with type III dental stone (Snow Rock; DK Mungyo). The mold was flasked with dental plaster (Mono 70; Yi Young-in Co., Ltd; Busan, Korea). The invested mold was placed in a curing unit (Curing unip; Shinseki international inc., Seoul, Korea) for 10–15 minutes for wax washing. A resin separator (Separating Fluid;

Ivoclar Vivadent AG) was applied to the mold, and the denture base resin (IvoBase Hybrid; Ivoclar Vivadent AG) was injected using an injection machine (IvoBase Injector; Ivoclar Vivadent AG; Figure 2). The specimens were then deflasked to complete the fabrication process (Figure 3). The compositions and manufacturers of the two denture base resins are listed in Table 1.

Table 1. Manufacturer and material components of denture base resins used in the study

Brand	Manufacturer	Material Components
IvoBase Hybrid	Ivoclar Vivadent AG Schaan, Liechtenstein	Powder: Polymethyl methacrylate; Plasticizer; Initiator; Pigments Liquid: Methyl methacrylate; Dimethacrylate; Catalyst
Denture 3D+	NextDent B.V. Soesterberg, The Netherlands	Ethoxylated bisphenol A dimethacrylate; 7,7,9-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1, 16-diyl bismethacrylate; 2-hydroxyethyl methacrylate; silicon dioxide, Diphenyl phosphine oxide; Titanium dioxide

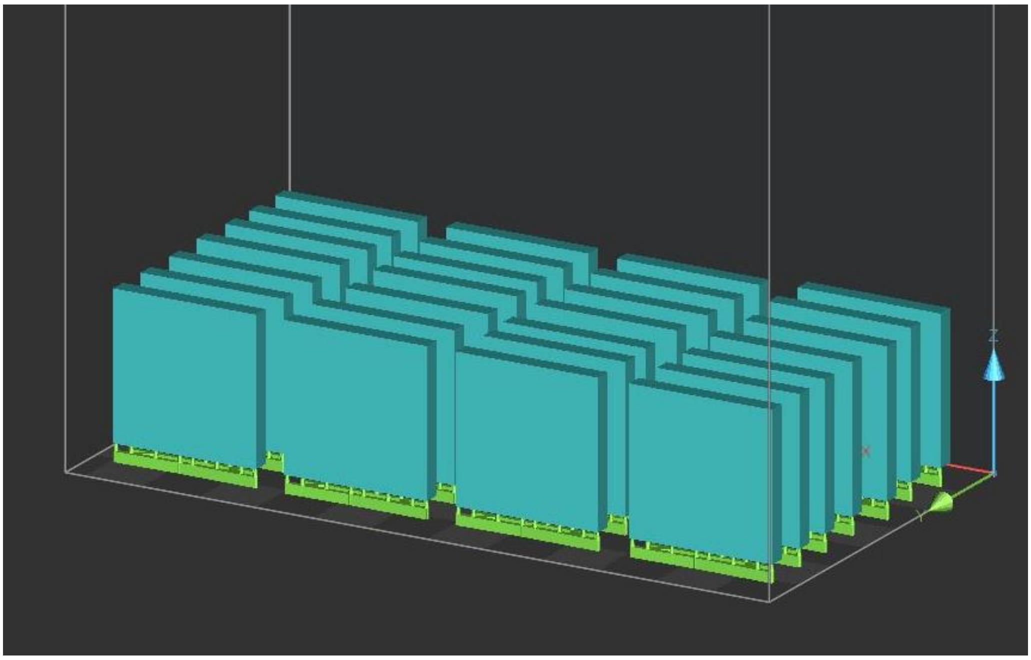

Figure 1. Screen capture showing the 3D printing orientation for Group TDP specimens. Support structures were attached to the narrow surface of the rectangular plate during the fabrication process.

Figure 2. The injection machine (IvoBase Injector; Ivoclar Vivadent AG, Schaan, Liechtenstein) used for the fabrication of Group HEA specimens.

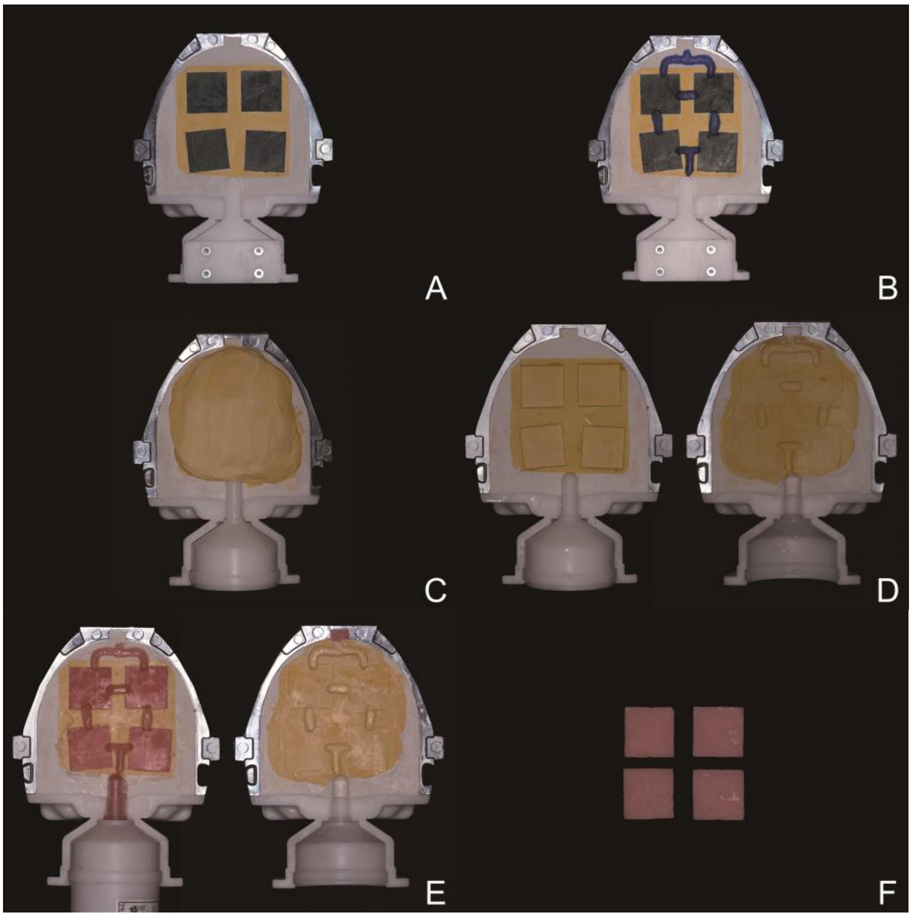

Figure 3. Tensile bond strength test sample preparation procedures for Group HEA. (A) Wax blocks embedded in the upper half of the flask. (B) Attachment of wax sprues. (C) Wax blocks and sprues covered with type III dental stone (Snow Rock; DK Mungyo, Gyeongsangnam-do, Korea). (D) Completion of the boil-out procedure showing both upper and lower flasks. (E) Resin injection process. (F) Final form of specimens.

2.2. Surface Treatment of Denture Base Resin Blocks

All resin specimens from both groups were polished with 600-grit silicon carbide sandpaper (Sic sandpaper; R&B, Daejeon, Korea) and stored in distilled water at room temperature for 24 hours. One-third of the specimens received no additional surface treatment (Group N). Another one-third of the specimens were sandblasted for 10 seconds using 110 μm aluminum oxide (Al_2O_3) (Cobra abrasive 110 μm; Renfert, Hilzingen, Germany). Residual Al_2O_3 particles were removed using a dental steam cleaner (Warmer's; Hub Dentech, Seoul, Korea), followed by air drying with an air gun (Group S). For the final one-third of the specimens, a bonding agent (Clearfil SE Bond; Kuraray Co., Tokyo, Japan) was applied and light-cured for 10 seconds (Group B).

2.3. Application of the Resilient Denture Liner

Each tensile bond strength test required a pair of denture base resin specimens. A 10 mm × 3 mm cylindrical polytetrafluoroethylene (PTFE) collar was placed on top of one resin specimen, and the resilient denture liner (Coe-Soft; GC, Tokyo, Japan) was mixed in a ratio of 11 g of powder to 8ml of liquid (Table 2). The liner material was poured into the PTFE cylinder, and another resin specimen was positioned on top. Pressure was applied for 5 minutes to ensure firmly attachment of the two resin specimens. A total of 12 assembled specimens were prepared for each group (Figure 4). Excess denture liner material was removed using a scalpel, and the assembled specimens were stored at room temperature for 24 hours prior to testing.

Table 2. Manufacturer and material components of the resilient denture liner used in the study

Brand	Manufacturer	Material Components
Coe-soft	GC Tokyo, Japan	Liquid: Di-n-Butyl phtha-late; Ethyl alcohol; Benzyl salicylate Powder: Polyethyl methacrylate; Zinc undecylenate

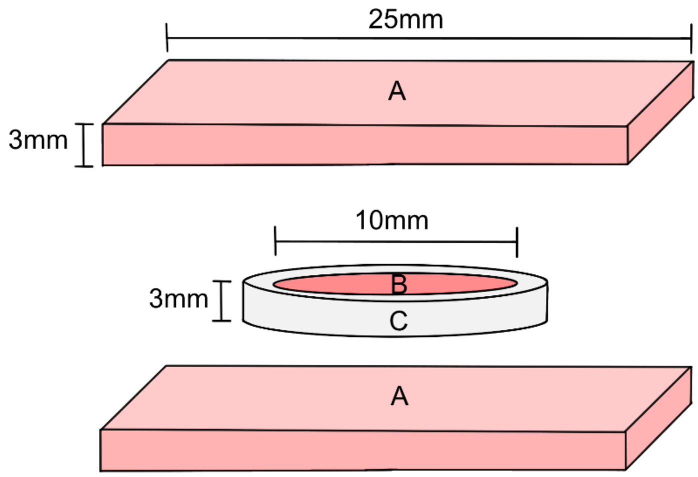

Figure 4. Structure of specimens prepared for the tensile bond strength test. (A) Denture base resins. (B) Resilient denture liner. (C) Polytetrafluoroethylene ring.

2.4. Thermocycling

Half of the specimens in each group underwent thermocycling using a thermocycling machine (TW-D813; Taewontech, Gyeonggi-do, Korea). Specimens without thermocycling were designated as Group BEF, while thermocycled specimens were classified as Group AFT. The thermocycling process consisted of immersion in a 5 ℃ water bath for 30 seconds, followed by a 5-second rest period, and then immersion in a 55 ℃ water bath for another 30 seconds. This cycle was repeated for a total of 3,000 cycles.

2.5. Tensile Bond Strength Test and Failure Analysis

The tensile bond strength test was performed using a custom jig on a universal testing machine (Instron 3366; Instron Corporation, Norwood, MA) at a crosshead speed of 10 mm/min (Figure 5-6). Tensile bond strength values were calculated in MPa using the following formula:

$$\text{Tensile bond strength} = \frac{\text{Greatest load prior to failure kilogram force (N)}}{\text{Cross-sectional area in centimeter square mm}^2}$$

Following the tensile bond strength tests, failure modes were analyzed using field emission scanning electron microscopy (FE-SEM) (JSM-7610F-plus; JEOL, Tokyo, Japan) at ×100 magnification. The failure modes were classified as adhesive failure, defined as a failure at the interfacial bond between the resin and the resilient denture liner; cohesive failure, characterized as a fracture within either the denture base resin or the resilient denture liner; and mixed failure, where both adhesive and cohesive failures were observed within the same specimen.

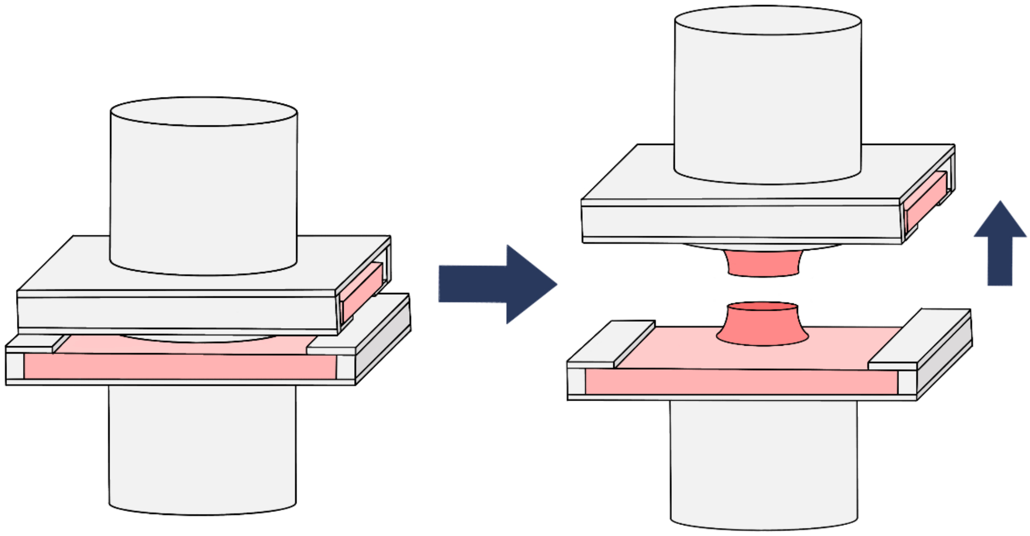

Figure 5. Schematic diagram illustrating the procedures for evaluating tensile bond strength, including specimen setup and testing process.

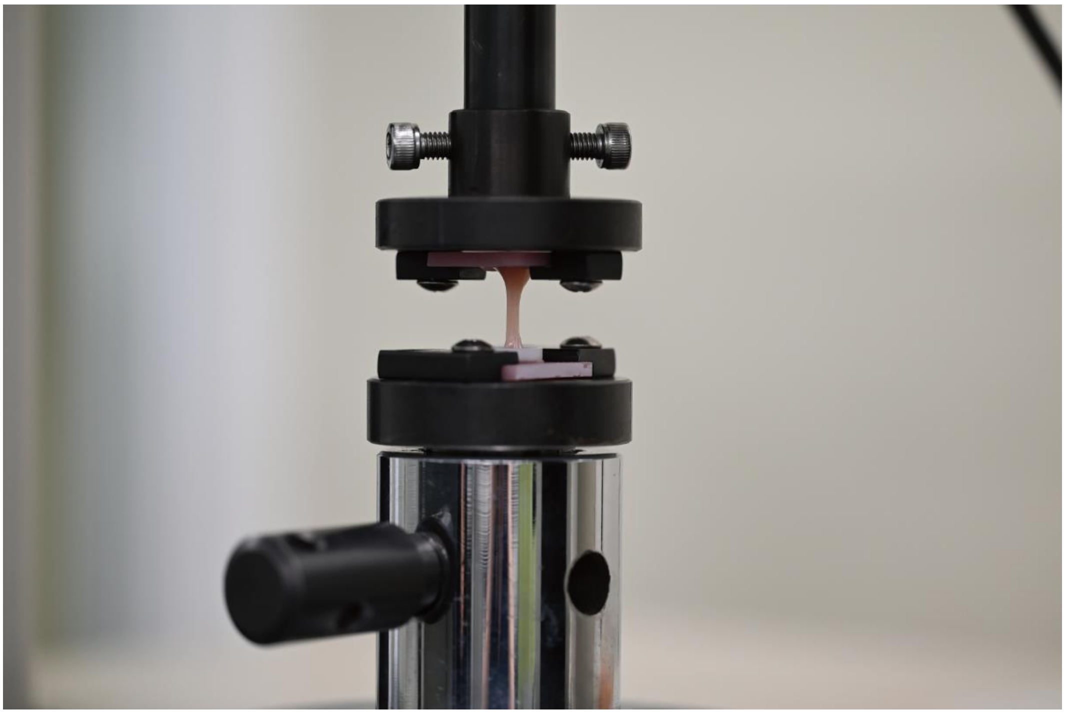

Figure 6. Representative image showing the tensile bond strength experiment in progress.

2.6. Statistical Analysis

Each subgroup was defined based on combinations of group names. Statistical analysis was performed using statistical software (SPSS version 26, IBM Co., Armonk, NY). A one-way analysis of variance (ANOVA) was used to evaluate the effect of surface treatment, while a two-way ANOVA was performed to assess the effects of thermocycling and denture base resin types. A *p*-value of less than 0.05 was considered statistically significant. Post-hoc analysis was performed using the Bonferroni method to identify significant differences between subgroups.

3. RESULTS

When the tensile bond strength values were analyzed by surface treatment types, irrespective of material type and thermocycling, no significant differences were observed among the three surface treatment methods ($n = 48$ for each group; $p = 0.641$; Figure 7).

When compared based on material type, without accounting for surface treatment and thermocycling, Group TDP exhibited significantly lower tensile bond strength values than Group HEA ($n = 72$ for each group; $p = 0.015$; Figure 8).

Comparisons of tensile bond strength before and after thermocycling, regardless of surface treatment or material type, revealed that values after thermocycling (Group AFT) were significantly lower than those before thermocycling (Group BEF) ($n = 72$ for each group; $p < 0.001$; Figure 9). Within Group TDP, tensile bond strength values were significantly lower after thermocycling compared to before thermocycling ($p = 0.016$). In contrast, no significant differences were observed in Group HEA before and after thermocycling ($p = 0.294$). Additionally, Group TDP showed significantly lower tensile bond strength values than Group HEA both before and after thermocycling ($n = 36$ for each group; $p = 0.050$ for BEF; $p = 0.001$ for AFT; Figure 10). Photographs of torn cross-sectional cohesive failure were observed across all groups, with no instances of adhesive or mixed failure modes detected (Figure 11).

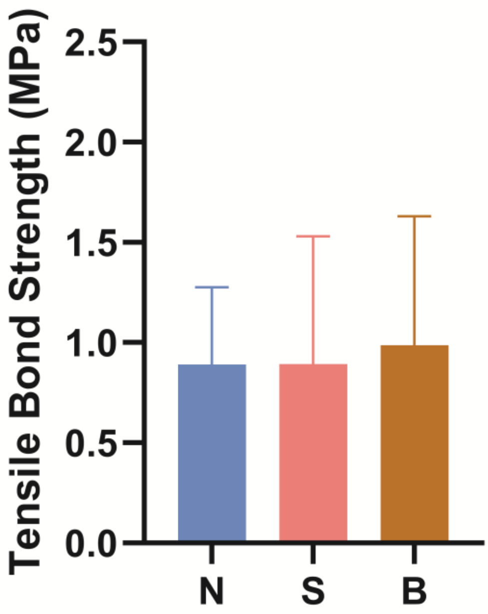

Figure 7. Tensile bond strength values based on surface treatment types. No significant differences were observed among the three groups (n = 48 per group). N, no treatment; S, sandblasting; B, application of bonding agent.

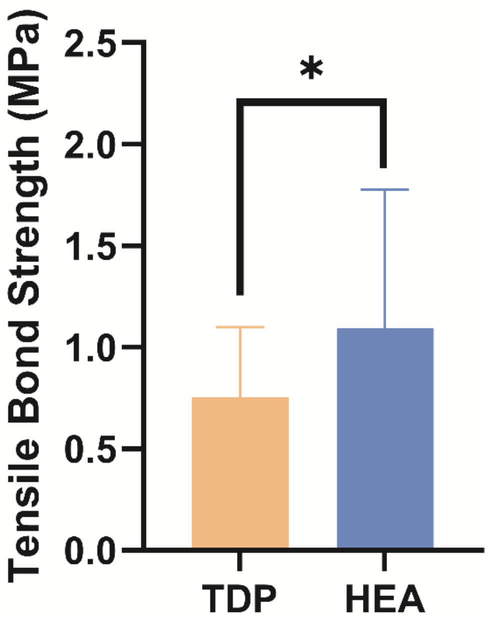

Figure 8. Tensile bond strength values based on denture base resin types. TDP, denture base resin group for 3D printing; HEA, denture base resin group for heat-cured resin. The asterisk indicates a statistically significant difference between the groups ($p < 0.05$).

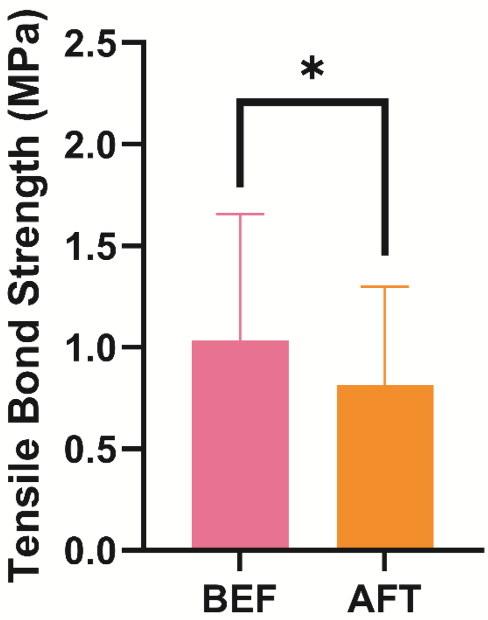

Figure 9. Tensile bond strength values based on thermocycling. BEF, group before thermocylcing; AFT, group of after thermocycling. The asterisk indicates a statistically significant difference between the groups ($p < 0.05$).

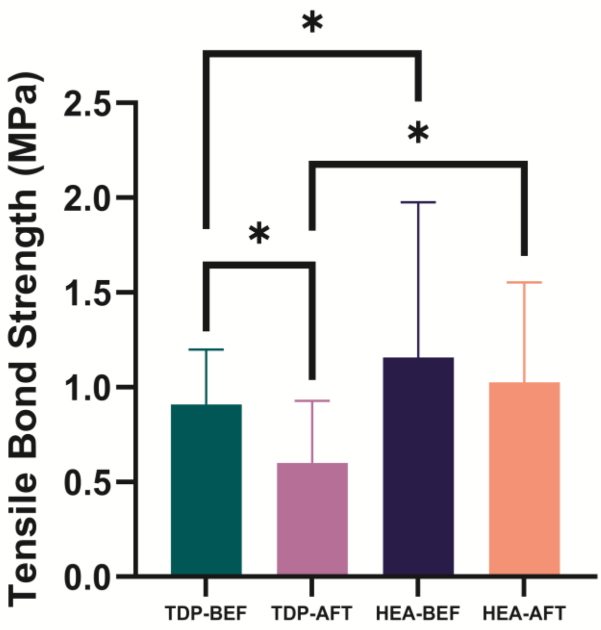

Figure 10. Tensile bond strength values based on denture base resin types and thermocycling. TDP, denture base resin group for 3D printing; HEA, denture base resin group for heat-cured resin; BEF, group before thermocycling; AFT, group after thermocycling. The asterisks indicate a statistically significant difference among the groups ($p < 0.05$).

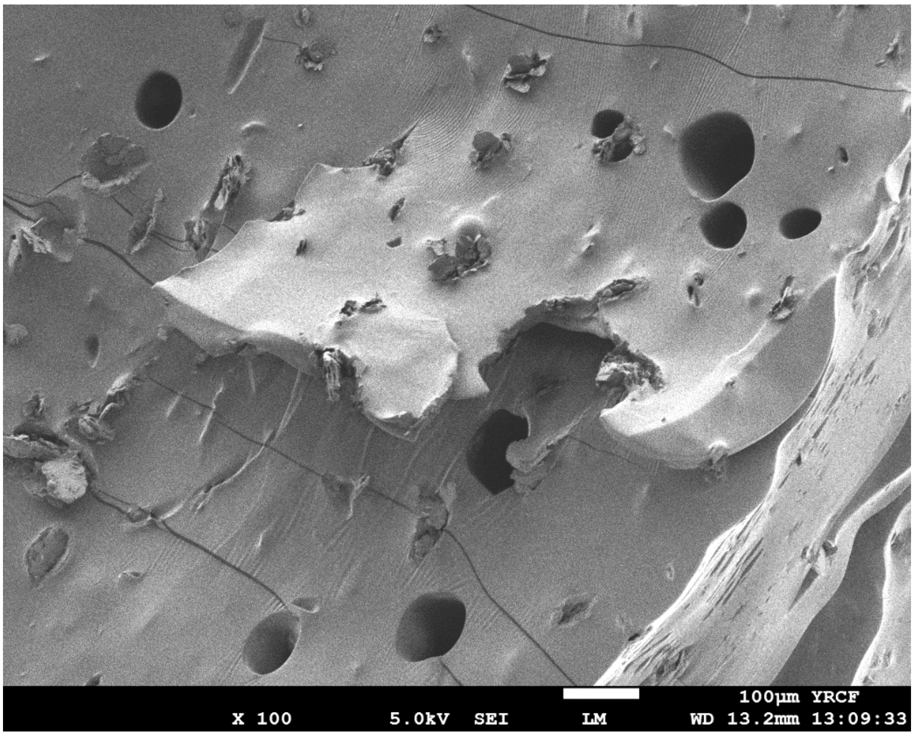

Figure 11. Representative image of the failure mode observed under field emission scanning electron microscopy (JSM-7610F-plus; JEOL, Tokyo, Japan) at ×100 magnification. The torn ridge surface is indicative of a cohesive failure mode.

4. DISCUSSION

The null hypothesis was partially rejected, as significant differences in tensile bond strength were observed based on material type and thermocycling. Digital workflows, such as utilizing intraoral scanners to obtain digital impressions and fabricating interim dentures via 3D printing, enhance clinical efficiency and value by minimizing the risk of cross-contamination compared to conventional impression-taking methods (Oyamada et al., 2021). Although digital interim dentures offer easy reproducibility, rapid tissue changes during the healing process may result in suboptimal fit when refabricating conventional IRDs. Continuously fabricating new interim dentures using intraoral scanners after each examination may not be recommended from economic or practical perspectives. Therefore, even when IRDs are fabricated digitally through 3D printing, incorporating a resilient denture liner, as traditionally practiced, may enhance patient comfort and tissue healing by preventing direct contact between the denture base and oral tissues. However, detachment of the liner from the prosthesis can compromise tissue stability and inconvenience patients, requiring additional clinic visits, and missing these visits could adversely affect oral health (Kattadiyil et al., 2017).

The oral cavity experiences significant temperature fluctuations due to consumption of hot or cold foods and beverages, making materials that maintain bond strength under thermal stress essential for prosthesis longevity. Thermocycling was employed to simulate these thermal stresses experienced by dental prostheses. Each 10,000 cycles corresponds to approximately one year of usage, and therefore, 3,000 cycles represent 3-4 months, aligning with the typical service period of resilient liners(Gale and Darvell, 1999; Swoope et al., 1974).

This study observed a decrease in bond strength after thermocycling. Previous studies have reported that acrylic-based resilient liners absorb water and lose plasticizers upon exposure to moisture, leading to reduced strength (Garcia et al., 2003; Mert et al., 2023; Mese and Guzel, 2008). These phenomena likely explain the decrease in bond strength in Group TDP after thermocycling. Furthermore, the lower tensile bond strength in Group TDP compared to Group HEA after thermocycling suggest reduced long-term stability of 3D-printable denture base resins, whereas conventional heat-cured resins exhibited greater stability. Interestingly, Group HEA showed no significant differences in bond strength before and after thermocycling, which contrasts with previous findings. This discrepancy could be attributed to differences in experimental conditions, particularly thermocycling protocols (Janyaprasert et al., 2024).

The significant differences in tensile bond strength between conventional heat-cured and 3D-printable denture base resins indicate that intrinsic material properties influence their bonding behavior with resilient denture liners. This finding aligns with previous studies suggesting that the material characteristics of 3D-printable denture base resins can affect bond strength (Awad et al., 2023). Moreover, the observation that bond strength decreased only in Group TDP after thermocycling highlights that the chemical structure of

3D-printable resins may not favor a durable bond with resilient liners (Dimitrova et al., 2022; Naji, 2020; Perea-Lowery et al., 2021; Pianelli et al., 1999).

The lack of significant differences in tensile bond strength based on surface treatment aligns with previous studies reporting that sandblasting or bonding agents had no effect on heat-cured resins or even reduced strength in some cases (Akin et al., 2011; Gundogdu et al., 2014). Notably, for 3D-printed resin, which demonstrated weaker long-term strength compared to heat-cured resin in this study, alternative surface may be necessary to achieve comparable performance. Clinically, the bond strength between denture base resins and acrylic-based resilient lining materials is considered acceptable if it exceeds 0.44 MPa (Kawano et al., 1992). While this study did not identify an optimal surface treatment for both materials, the average bond strength in all groups exceeded 0.44 MPa, indicating that both materials are clinically applicable. The observation of cohesive failure in all specimens suggests that the bond strength between the denture base resin and the soft liner was sufficiently strong, reflecting a robust interface between the two materials. Since cohesive failure occurred consistently across different surface treatments, it can be inferred that surface treatment did not weaken the bond.

This study has some limitations, including the use of a single type of soft liner, which restricts the generalizability of the findings to other resilient lining materials. Furthermore, the experiments were conducted under specific laboratory conditions rather than real clinical environments, meaning the results may not fully represent clinical scenarios. Further research is needed to account for the complexity of clinical environments and to evaluate a wider range of lining materials and denture base resins. Nonetheless, this study is the first to experimentally evaluate 3D-printable denture base resins and surface treatments under ISO standards. While 3D printing offers various advantages, such as ease of reproduction, caution should be exercised when using resilient denture liners due to potential impacts on bond strength. As 3D printing technology continues to advance, it is likely to find broader applications in prosthodontics. Future studies should aim to improve the durability of resilient liners, exploring surface treatment modifications such as creating notches in the denture base resins or employing advanced mechanical and chemical bonding techniques to enhance adhesion in removable dentures.

5. CONCLUSION

1. The tensile bond strength of the 3D-printable denture base resin with the resilient denture liner was significantly lower than that of the heat-cured denture base resin after thermocycling.

2. The tensile bond strength of the 3D-printable denture base resin bonded to the resilient denture liner decreased significantly after thermocycling compared to its initial strength before thermocycling.

3. Despite the observed differences, both types of denture base resins demonstrated tensile bond strengths that are clinically acceptable for attaching the resilient denture liner.

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ABSTRACT IN KOREAN

두 종류의 의치상용 레진과 연질 이장재 사이의 인장결합강도 평가

본 연구의 목적은 전통적 열중합형 의치상용 레진과 적층제조용 의치상용 레진을 연질 이장재와 결합했을 때 나타나는 인장결합강도를 표면처리 방법과 열순환 처리 적용 유무에 따라 비교하는 것이다. 컴퓨터 기반 설계(computer-aided design) 프로그램을 이용하여 25 mm × 25 mm × 3 mm 크기의 직육면체를 디자인하고, 이를 standard tessellation language (STL) 파일로 저장하였다. 적층 제조용 의치상용 레진군(TDP 군)은 3D 프린터를 이용하여 STL 파일을 직접 출력하여 시편을 제작하였고(n=144), 열중합형 의치상용 레진군(HEA 군)은 동일한 STL 파일을 이용해 왁스로 절삭 가공한 후 이를 치과용 석고와 경석고로 매몰한 뒤, 주입기를 사용하여 열중합형 의치상용 레진을 주입하여 시편을 제작하였다(n=144). 제작된 모든 시편은 600 grit 의 연마지로 연마한 후 실온의 증류수에 24 시간 동안 보관하였다. 각 인장결합강도 실험에는 한 쌍, 즉 두 개의 시편이 필요하므로 실제로는 TDP 군과 HEA 군 각각 72 개의 시편이 준비되었다고 할 수 있다. 시편은 하위 군으로 나뉘어, N 군은 표면처리를 하지 않았고, S 군은 레진

표면에 110 ㎛ 크기의 산화알루미늄을 10 초간 분사하였으며, B 군은 본딩제를 도포한 후 10 초간 광중합을 수행하였다. 폴리테트라플루오로에틸렌 링을 이용해 연질 이장재를 흘려 넣어 한 쌍의 시편을 결합한 뒤 이를 실온에서 24 시간 동안 보관하였으며, 전체 시편의 절반은 3,000 회의 열순환 처리를 받았다. 인장결합강도 실험은 만능 재료 시험기(universal testing machine)를 사용하여 분당 10mm 의 속도로 진행되었다. 일원분산분석을 통해 표면처리 방법이 인장결합강도에 미치는 영향을 평가하였으며, 이원분산분석을 통해 열순환 처리 유무와 의치상용 레진의 종류에 따른 인장결합강도의 차이를 분석하였다. 유의 수준은 0.05 로 설정하였고, 본페로니(Bonferroni) 방법을 사용하여 사후 검정을 진행하였다. 연구결과, 표면처리 방법 간의 인장결합강도에는 유의미한 차이가 나타나지 않았으며, TDP 군은 열순환 처리 후 인장결합강도가 유의미하게 감소한 반면(p=0.016), HEA 군은 열순환 처리 전후로 유의미한 차이를 보이지 않았다(p=0.294). 또한, 열순환 처리 전과 후 모두에서 TDP 군은 HEA 군에 비해 유의미하게 낮은 인장결합강도를 보였다($p<0.05$). 그러나 두 종류의 의치상용 레진 모두 연질 이장재와의 인장결합강도가 임상적으로 활용 가능한 범위에 있는 것으로 판단된다.

핵심되는 말: 3D 프린팅, 적층 제조, 연질 이장재, 인장결합강도, 열순환 처리, 표면처리, 의치상용 레진