Effect of surface treatment on shear bond strength of relining material and 3D-printed denture base

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PURPOSE. This study aimed to analyze the shear bond strength between the 3D-printed denture base and the chairside relining material, according to the surface treatment. **MATERIALS AND METHODS.** Cylindrical specimens were prepared using DENTCA Denture Base II. The experimental groups were divided into 6 (n = 10): no surface treatment (C), Tokuyama Rebase II Normal adhesive (A), sandblasting (P), sandblasting and adhesive (PA), sandblasting and silane (PS), and the Rocatec system (PPS). After bonding the chairside relining material to the center of the specimens in a cylindrical shape, they were stored in distilled water for 24 hours. Shear bond strength was measured using a universal testing machine, and failure mode was analyzed with a scanning electron microscope. Shear bond strength values were analyzed using one-way analysis of variance, and Tukey's honest significant difference test was used for post-hoc analysis ($P <$ .05). **RESULTS.** Group PPS exhibited significantly higher shear bond strength than all other groups. Groups P and PA displayed significantly higher bond strengths than the control group. There were no significant differences between groups PS and A compared to the control group. Regarding the failure mode, adhesive failure occurred primarily in groups C and A, and mixed failure mainly in groups P, PA, PS, and PPS. **CONCLUSION.** The shear bond strength between the 3D-printed denture base and the chairside relining material exhibited significant differences according to the surface treatment methods. It is believed that excellent adhesive strength will be obtained when the Rocatec system is applied to 3D-printed dentures in clinical practice. [J Adv Prosthodont 2022;14:262-72]

KEYWORDS
3D printing; Surface treatment; Computer-aided design; Denture base; Rocatec system

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INTRODUCTION

As life expectancy of individuals increases worldwide, the demand for removable dental prostheses is increasing.[1,2] However, when complete dentures

are manufactured conventionally for edentulous patients, who are primarily older adults, the required number of visits can be burdensome.[3] In addition, if the complete denture is lost or fractured, it is difficult to have it remade.[4] With the development of current technology, precise complete dentures can be manufactured using computer-aided design/computer-aided manufacturing (CAD-CAM), with fewer visits. Also, because the data can be stored, dentures can be easily remanufactured.[5-9]

There are subtractive and additive methods in CAM technology. The subtractive procedure for making complete dentures involves cutting from large resin blocks using a milling bur.[6] Because resin blocks that have already been polymerized are used, their mechanical properties are superior to those of conventional heat-cured resins.[10] However, it is not possible to reproduce a component that is smaller than the size of the milling bur, and there is considerable wastage of materials. Conversely, additive technology is a process of stacking up layers, so there is little wastage of materials, and small parts can be produced.[11,12] Furthermore, there are also several output methods for additive processes, among which stereolithography apparatus (SLA) and digital light processing (DLP) using light polymerization are widely used in dentistry.[13,14] The SLA method uses a laser beam to polymerize point by point, and the DLP method achieves polymerization using a projector.[12,13,15]

You et al.[13] evaluated the adaptation of denture base manufactured wax patterns by subtractive, SLA and DLP, casting it into metal bases, and measuring the inner gap when manufacturing the maxillary complete denture. The denture bases manufactured using the SLA method had less inner gap than those manufactured using DLP and the subtractive method. Curved forms in the maxillary anterior and posterior residual ridge are difficult to reproduce with the milling bur. In addition, the SLA method can print a smooth surface finish and achieve consistent resolution regardless of the size of the output. The DLP method is light-cured with 2D pixel patterns; therefore, the larger the size of the output, the larger the pixel size and the lower resolution. When manufacturing the maxillary complete dentures, all three manufacturing methods exhibit clinically acceptable adaptation, but SLA is recommended.

Removable prosthesis may decrease adaptation by time. Aging and resorption of the residual ridge[16] result in a decrease of occlusal vertical dimension, loss of retention and stability, change in occlusal plane, and sore spots. To address these problems, relining, rebasing, or refabrication should be considered.[17] Among these three treatments, relining is the most frequently used method and may be the most appropriate for mild or moderate ridge resorption. Relining dentures can be performed by direct or indirect methods. The direct method, which is inserted directly in the mouth of a patient, is widely used because it is faster and simpler than the indirect method.[18]

Previous studies compared tensile bond strength between materials for direct relining and 3D-printed denture bases. Denture bases made by subtractive methods, and heat-cured resin, the 3D-printed denture base possessed low bond strength. This applied to both DLP and SLA methods, and there were significant differences.[19,20] Factors affecting the bond strength include the chemical structure of the denture bases, chemical structure of the relining materials, reaction of bonding agents, linear thickness of the denture lining material, tear strength, and thermal stress.[21,22] Low tensile bond strength of 3D printing denture bases under same conditions as the linear thickness, tear strength, and thermal stress of direct relining materials appears to be due to differences in the chemical structure between denture bases and lining materials, and reaction with bonding agents. In particular, the 3D printing denture bases are stable to methyl methacrylate (MMA) monomer.[23] The chemical structure of the denture bases and the relining materials cannot be changed due to the inherent properties of the materials, and the bond strength can be increased by improving the reaction between the denture bases and adhesives. However, there are limited studies on the elevating reaction of the bonding agent in the 3D printing resin.

The purpose of this study was to compare the shear bond strength of hard relining material to 3D printing resin printed by SLA method, depending on surface treatment. The surface treatment methods included sandblasting, silanizing, application of adhesive which used for direct relining resin, and the Rocatec

system (3M ESPE, Seefeld, Germany). The null hypothesis was that there was no difference in shear bond strength between the chairside relining material and the 3D-printed denture base depending on the surface treatment method.

MATERIALS AND METHODS

Sixty denture base resin specimens were printed by SLA method using DENTCA Denture Base II (DENTCA Inc., Torrance, CA, USA). Tokuyama Rebase II Normal (Tokuyama Dental Corp., Tokyo, Japan) had been used for chairside relining material. Table 1 summarizes the brand names, manufacturers, and components of the materials used in this study. The denture base resin was designed as a cylindrical shape with a diameter of 20.0 mm and a height of 14.0 mm as a standard tessellation language (STL) file, and then an SLA type 3D-printer (ZENITH U; Dentis, Daegu, Korea) was used. The layer thickness (100 μm) was set, supports were placed opposite to the testing side, and printed in 0°. After the supports were removed, the specimens were post-polymerized in glycerin at 80°C for 20 minutes to follow the manufacturer's instructions. The underside of the specimens was reversed and light-cured in a post-curing machine for 20 minutes in the same manner. To make the bottom surfaces parallel and flat to each other, they were polished with an automatic polishing device (LaboPol-5; Struers, Copenhagen, Denmark). Then, the specimens were cleaned using an ultrasonic cleaner (SD-120H; Mujigae Co., Seoul, Korea) with distilled water for 20 minutes. For following ISO 10139-2, they were stored in distilled water at 37°C for 30 days.[24] Depending on the surface treatment method, they were divided into 6 groups (Table 2).

Table 3 describes the components and manufacturers of surface treatment agents, Rocatec Pre, Rocate Soft, and ESPE Sil. The following surface treatments were performed for each group.

(1) Group 1 (C): As a control group, no surface treatment was performed, and specimens were dried

Table 1. Composition and manufacturer's information of materials used in this study

Material		Composition	Manufacturer
Denture base	DENTCA Denture Base II	Methacrylate monomer Diurethane dimethacrylate (DUDMA) Propylidynetrimethyl trimethacrylate	DENTCA Inc., Torrance, CA, USA
Chairside relining material	Tokuyama Rebase II Normal	Adhesive: Acetone, Ethyl acetate	Tokuyama Dental Corp., Tokyo, Japan
		Powder: Polyethyl methacrylate (PEMA), Benzoyl peroxide	
		Liquid: 2-(Acetoactoxy) ethyl methacrylate, 1,9-Nonanediol dimethacrylate	
		Hardener: Sodium sulfite, Sodium bicarbonate	

Table 2. Classification of test groups

Group (n = 10)	Abbreviation	Surface treatment
Group 1 (Control)	C	No surface treatment
Group 2	A	Tokuyama Rebase II Normal adhesive
Group 3	P	Rocatec Pre
Group 4	PA	Rocatec Pre + Tokuyama Rebase II Normal adhesive
Group 5	PS	Rocatec Pre + ESPE Sil
Group 6	PPS	Rocatec Pre + Rocatec Plus + ESPE Sil

Table 3. Composition and manufacturer's information of surface treatment materials

Material		Composition	Manufacturer
Sandblasting	Rocatec Pre	High-purity aluminium oxide (110 μm)	
Silica coating	Rocatec Plus	Silica-modified aluminium oxide (110 μm)	3M ESPE, Seefeld, Germany
Silane coupling agent	ESPE Sil	3-Methacryloxypropyltrimethoxysilane Ethanol	

with oil-free compressed air.

(2) Group 2 (A): After drying the specimens, Tokuyama Rebase II Normal adhesive was applied for 20 seconds according to the manufacturer's instructions and dried with compressed air.

(3) Group 3 (P): After drying, as directed by the manufacturer's instructions, Rocatec Pre was blasted at 10.0 mm from the specimens at a pressure of 2.8 bar for 15 seconds. They were washed for 10 seconds using a steam cleaner (SESY2014 New Beginning; SEKI Industry, Seoul, Korea) and dried with compressed air.

(4) Group 4 (PA): The specimens were sandblasted with Rocatec Pre, washed using a steam cleaner for 10 seconds, dried, and then Tokuyama Rebase II Normal adhesive was applied for 20 seconds and dried with compressed air.

(5) Group 5 (PS): After surface treatment in the same manner as in Group 3, a silane coupling agent, ESPE Sil was applied and dried for 5 minutes.

(6) Group 6 (PPS): Tribochemical method, Rocatec system, was used. After treatment in the same manner as in Group 3, Rocatec Plus (110 μm) was applied as a silica coating on the surface. Rocatec Plus was blasted for 15 seconds at a pressure of 2.8 bar from a distance of 10.0 mm according to the manufacturer's instructions. After cleaning the surface with compressed air, ESPE Sil was applied and dried for 5 minutes without contamination.

A silicone mold (Mold master ultra; Molkang, Yangju, Korea) was manufactured so that the Tokuyama Rebase II Normal could adhere to the center of the specimen in a cylindrical shape with a diameter of 3.0 mm and a height of 3.0 mm (Fig. 1). After appropriate surface treatment to each group, Tokuyama Rebase
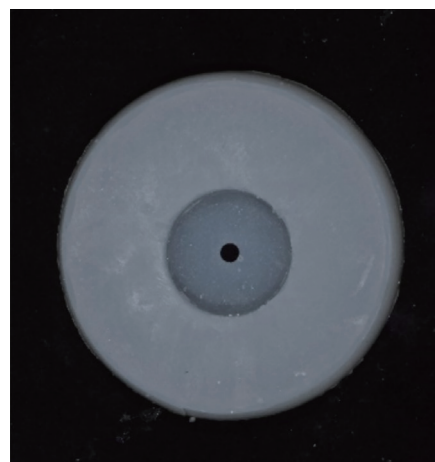

Fig. 1. Silicone mold for bonding chairside relining material.

II Normal was mixed and applied on the specimens according to the manufacturer's instructions. It was gently mixed for 10 seconds to avoid the formation of bubbles, applied within 60 seconds, and polymerized for 8 minutes. The specimens were carefully separated from the mold and the excess was carefully removed with a surgical blade (No.25; Feather Safety Razor Co., Osaka, Japan). Tokuso Resin Hardener II (1 spoon) was added to water (200 mL) at 60°C, and the specimens were immersed for 3 minutes. They were then stored in distilled water at 37°C for 24 hours.

A universal testing machine (Instron 3344; Instron Co., Canton, OH, USA) was used to evaluate the shear bond strengths (Fig. 2). The crosshead speed was set at 0.5 mm/min, and the maximum load until fracture of the specimens was recorded in Newton (N). The shear bond strength was calculated using the equation below:

$$\text{Shear bond strength (MPa)} = \frac{N}{A}$$

N = maximum load (N)
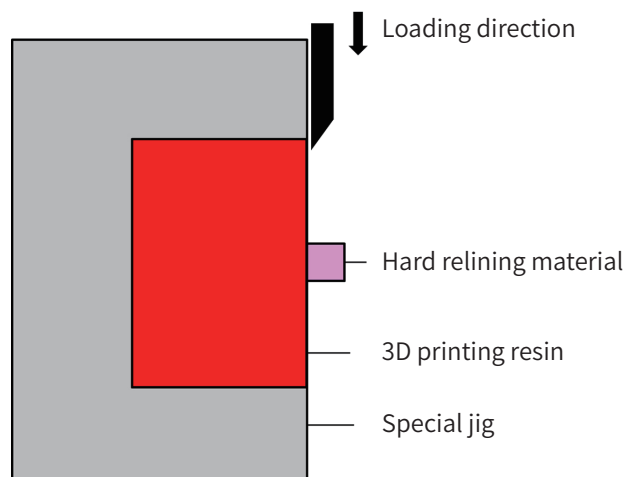A = Adhesive area (mm^2) = 7.07 mm^2

Fig. 2. Schematic diagram of the experimental setup to measure the shear bond strength.

To analyze the failure mode, a scanning electron microscope (ZEISS GeminiSEM 500; Carl Zeiss Co., Oberkochen, Germnay) was used. The failure mode was analyzed at ×50 magnification and classified as follows: cohesive failure occurring within denture base or relining material, adhesive failure occurring at the interface between denture base and relining material, and mixed failure. Combination of cohesive and adhesive failure was regarded as mixed failure.

Shear bond strength was statistically analyzed using IBM SPSS Statistics v28.0 (IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test was used for normality and the one-way ANOVA test was used to analyze the differences among the groups. Post-hoc analysis was performed using the Tukey honest significant difference (HSD) test (α = .05). Fisher's Exact test was performed to analyze the failure mode (α = .05).

RESULTS

Figure 3 shows the means and standard deviations of shear bond strength of each group measured using the universal testing machine. The one-way ANOVA test was performed and there were significant differences among the groups. Table 4 shows significant differences between each group using Tukey's HSD test.

Group PPS using the Rocatec system exhibited the highest shear bond strength, which was significantly different from the other 5 groups (P < .05). Next, group PA, which underwent sandblasting and adhesive application, displayed high bond strength, but there was no significant difference from group P, which only underwent sandblasting (P = .863). However, group PA exhibited a significant difference from group PS treated with sandblasting and silane (P = .007). Group
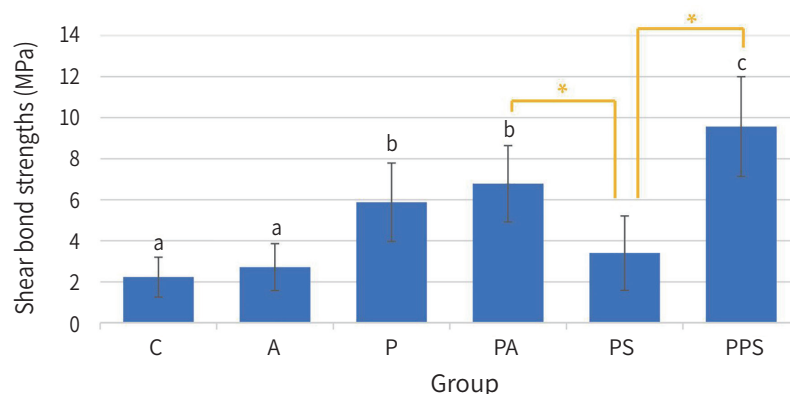

Fig. 3. Means and standard deviations of shear bond strengths for all groups.
C: No surface treatment, A: Tokuyama Rebase II Normal adhesive, P: Rocatec Pre, PA: Rocatec Pre + Tokuyama Rebase II normal adhesive, PS: Rocatec Pre + ESPE Sil, PPS: Rocatec Pre + Rocatec Plus + ESPE Sil.
Different single letters denote significant difference between each group (P < .05).
* denotes a significant difference between each group (P < .05).

Table 4. Tukey's honest significant difference (HSD) test of shear bond strength between groups

				P value		
Group	C	A	P	PA	PS	PPS
C			*	*		*
A	.989		*	*		*
P	<.001*	.002*				*
PA	<.001*	<.001*	.863		*	*
PS	.293	.668	.133	.007*		*
PPS	<.001*	<.001*	<.001*	.010*	<.001*	

C: No surface treatment, A: Tokuyama Rebase II Normal adhesive, P: Rocatec Pre, PA: Rocatec Pre + Tokuyama Rebase II normal adhesive, PS: Rocatec Pre +
ESPE Sil, PPS: Rocatec Pre + Rocatec Plus + ESPE Sil.
* denotes a significant difference between each group (*P* < .05).

P, which displayed the third highest value, did not show a significant difference from the PS group (*P* = .133), but there were significant differences between group C set as a control group and group A to which only adhesive was applied (*P* < .05). Group PS exhibited no significant difference from group C (*P* = .293) and group A with adhesive only (*P* = .668). There was no significant difference between groups A and C (*P* = .989).

Figure 4 illustrates the failure mode distribution in each group. Figure 5 shows dominant failure modes in each group using SEM. Adhesive failure occurred in 100% of the control group, and in group A, where only adhesive was applied, 80% of adhesive failure and 20% of mixed failure occurred. In the sandblasting group (P), adhesive failure was reduced to 40%, and mixed failure (60%) was primarily observed. In groups PA, PS, and PPS, mixed failure was dominantly found, with percentage of 70%, 70%, and 80%, respectively. Only one cohesive failure was observed in the 6 groups, which was in the Rocatec system group (PPS). This cohesive failure occurred in the hard relining material layer. The results of Fisher's Exact test showed significant differences between each group. Group PPS exhibited significant difference from group C (*P* < .001) and A (*P* = .005).
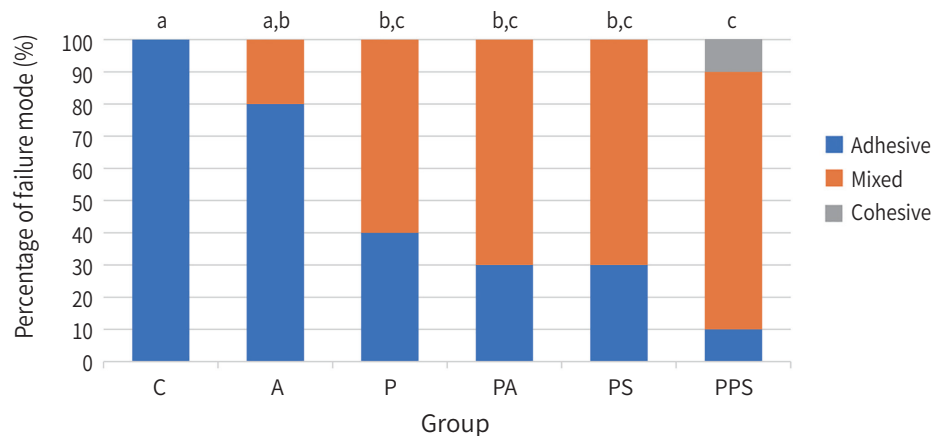

Fig. 4. Failure mode analysis of all test groups.
C: No surface treatment, A: Tokuyama Rebase II Normal adhesive, P: Rocatec Pre, PA: Rocatec Pre + Tokuyama Rebase II
normal adhesive, PS: Rocatec Pre + ESPE Sil, PPS: Rocatec Pre + Rocatec Plus + ESPE Sil.
Different single letters denote significant difference between each group (*P* < .05).
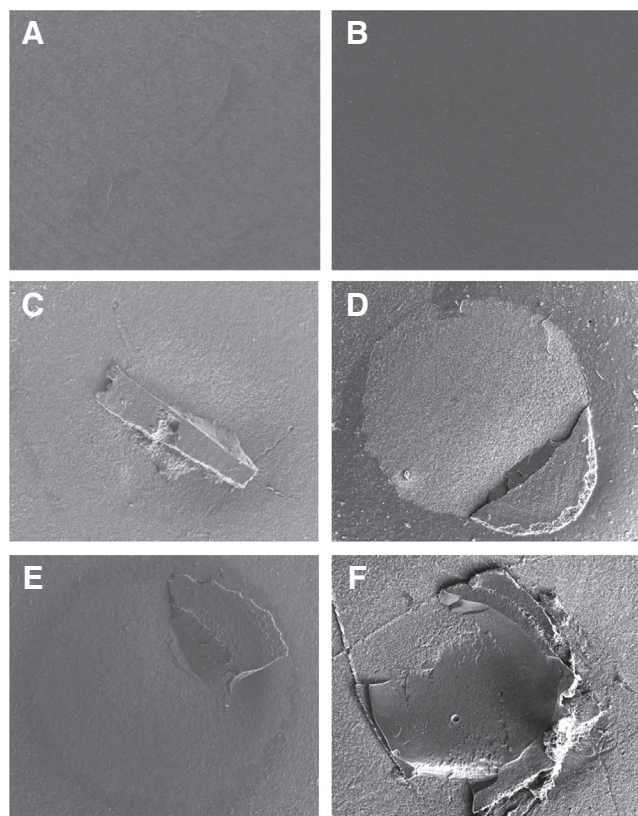
Fig. 5. SEM images of dominant failure mode in each group (magnification ×50). (A) Group C: No surface treatment : Adhesive failure, (B) Group A: Tokuyama Rebase II Normal adhesive : Adhesive failure, (C) Group P: Rocatec Pre : Mixed failure, (D) Group PA: Rocatec Pre + Tokuyama Rebase II normal adhesive : Mixed failure, (E) Group PS: Rocatec Pre + ESPE Sil : Mixed failure, (F) Group PPS: Rocatec Pre + Rocatec Plus + ESPE Sil : Mixed failure.

DISCUSSION

Previous studies have demonstrated that the more similar the chemical structure between the denture base and the relining material, the higher the bond strength.[23,25] However, the chemical structure is an inherent property of materials, so it is not a factor that clinicians can alter in clinical situations in which hard relining material is limited. In this study, the same 3D printing resin and material for chairside relining were used. To increase reaction of the adhesive to the resin printed using the SLA method, various surface treatments were applied to evaluate bond strength. The null hypothesis was partially rejected.

The mechanism of adhesion between the conventional poly(methyl methacrylate) (PMMA) denture base and the chairside relining material is that when the solvent or monomer is applied to the surface of the denture base, swelling occurs in the base resin. Subsequently, when the relining material is applied, the penetration and diffusion of the monomers occur, and an interpenetrating polymer network (IPN) is formed through polymerization.[26] Since the IPN thickness varies depending on swelling of the PMMA and diffusion of the monomer, it affects bond strength.[27] It was reported that solvents such as acetone, chloroform, or dichloromethane increase swelling of the PMMA base and enhance monomer diffusion, thereby enhancing the adhesive strength with the relining resin.[28] However, in this study, an adhesive composed of acetone and ethyl acetate was applied to improve bond strength, but there was no significant difference compared to that of the control group. In a study by Wemken et al.,[25] resin base surface morphology was evaluated using an optical 3D profiler after immersing the monomer or acetone for 1 hour, using heat-cured, subtractive, and DLP resin. Heat-cured PMMA resin, which was immersed in acetone was changed the most, and the surface morphology was also altered when immersed in the monomer. Furthermore, there was a significant difference in subtractive PMMA resin after soaking in acetone, but no difference was observed when the monomer was applied. It is believed that less swelling occurred in the subtractive resin because the amount of residual monomer was small, and heat-cured denture base resin was easily dissolved and swollen due to linear polymerization of the polymer. However, urethane dimethacrylate (UDMA), DLP resin, did not show any change in the surface morphology even when immersed in monomer and acetone. It was reported that 3D-printed resin is very stable to monomer and acetone because of the cross-linked polymer. Similar to this study, it was shown that adhesive in the Tokuyama rebase II kit did not improve the swelling due to cross-linking of the diurethane dimethacrylate (DUDMA) denture base resin.

In addition to the adhesive, air abrasion, silane application, and silica coating were done to improve

bond strength. Air abrasion removes impurities from the denture surface and improves mechanical bonding through increasing roughness and bonding area.[29] In this study, the surface roughness of printing resin was increased by sandblasting with Al_2O_3 (110 µm). In addition, for the sandblasting with adhesive group, as roughness increased, bond strength increased. Li *et al.*[30] measured tensile bond strength using the same printing resin base with thermocycling according to the surface treatment: no surface treatment, monomer application, air abrasion with Al_2O_3 (125 µm). The highest bond strength was observed in the air abrasion group, and there was a significant difference. Lim and Shin[31] compared shear bond strength according to surface treatment to 3D-printed provisional resin with repair resin, composed of PMMA, as follows: no surface treatment, soaking in monomer, sandblasting with Al_2O_3 (50 µm), and sandblasting with monomer application. All four groups exhibited no significant differences. The reason for different result was considered to be the difference in the Al_2O_3 size and flowability of the repair material. The better flowability, the easier to penetrate into the irregular surface created by sandblasting, and the better mechanical bonding obtained.[32,33] In the study by Akin *et al.*,[34] the tensile bond strength between PMMA denture base and soft lining material according to size of Al_2O_3 was measured. Only the group sandblasted with Al_2O_3 (120 µm) showed significantly higher bond strength compared to no surface treatment, Al_2O_3 (50 µm), Al_2O_3 (60 µm), and Al_2O_3 (250 µm) groups. The Rocatec Pre is Al_2O_3 (110 µm), and it is believed that a significant difference was observed because Tokuyama Rebase II had the appropriate flowability to penetrate. It is thought that further study of bond strength according to the flowability of the lining material and the size of Al_2O_3 is required.

Silane was used to form chemical bonds between the denture base and the chairside relining resin. In previous studies, silane could only form chemical bonds with organic resins in ceramic materials containing a lot of inorganic silica,[35] and the ESPE Sil manufacturer's manual also emphasized that it reacts with silica on the surface of the substrate. ESPE Sil has two functional groups with different polarities. The alkoxy group of the silane forms chemical bond

with the hydroxide group on the inorganic surface and the water molecule, and the methacrylate group on the opposite side forms copolymerization with the resin monomer, forming a chemical bond between the substrate and the resin. Jeong and Kim[36] reported that there was no change in bond strength when silane was applied to temporary resins printed by SLA and DLP methods. It is believed that because there is little or no inorganic filler to react with silane in the 3D-printing resin. DENTCA Denture Base II used in this study also did not increase bond strength because the content of filler for chemical bonding was insufficient. Moreover, the bond strength was reduced by silane acting as an impurity between sandblasted resin and relining material. Another reason is that, according to Bayati *et al.*,[37] bubbles are generated due to a chemical reaction in the primer-treated PMMA or UDMA specimens, and these bubbles serve as a starting point for fracture and reduce bond strength. Although silane conforms to the claim of reducing bond strength, the adhesive used in this study did not show any decrease in bond strength. Another possible reason is that the concentration of silane applied is not appropriate. It has been reported that when the concentration of silane is too high or too low, the bond strength between the inorganic material and the silane is not strong and the silane layer itself acts as a weak part.[38] Only ESPE Sil was used in this study, and additional research on the bond strength according to the silane concentration in 3D printing resin is required.

The silica coating method was originally introduced to improve bond strength between metal and resin veneers.[39] The Rocatec system using this surface treatment forms chemical bonds between silane and partially silica-coated surface. First, impurities are removed by sandblasting with Al_2O_3 (110 µm), and roughness of the surface is increased; mechanical retention is improved while the surface has a uniform pattern. Next, silica-modified Al_2O_3 (110 µm) is used for silica coating, and silica particles are attached to the surface and can combine with silane. A method of forming chemical bonds by applying only physical energy without light or heat is called the tribochemical method.[40] According to the manufacturer's instructions, blast speed of the particles is important

because a high level of physical energy is required to obtain a chemical bond, and it should be sandblasted with pressure of at least 2.8 bar.

In several studies, it is reported that bond strength was improved by applying the silica coating method to various materials other than metal and ceramics. Park et al.[41] showed high shear bond strength when treated with the Rocatec or CoJet system (3M ESPE, Seefeld, Germany) on In-Ceram Zirconia specimens, and there were significant differences. Kümbüloğlu et al.[42] reported that tensile bond strength with self-cured relining materials increased after the Rocatec system was applied to thermoplastic polyamide and PMMA denture base resins. Therefore, the Rocatec system was also applied in this study; the 110 μm Rocatec system was applied instead of the CoJet system using 30 μm silica-modified Al_2O_3 because the denture base was large and thick. The Rocatec group in this study displayed a significantly higher shear bond strength compared with all the other groups. It is thought that mechanical retentions were increased with increased the surface irregularity, roughness, and bonding area by blasting Al_2O_3 and silica modified Al_2O_3. Moreover, chemical bonds with silane were formed as the silica content increased on the resin surface after silica coating.[43] However, since the silica coating method is sensitive to moisture, there may be differences in bond strength when directly relined in clinical situations. Therefore, in-depth studies that can reproduce in vivo conditions or moist environments are required in the future.

By analyzing the failure modes, surface treatments could affect shear bond strength with significant difference. Control group showed significant difference from groups P, PA, PS, and PPS. There was significant difference between group A and PPS. We observed that adhesive failure occurred mainly in groups C and A, and mixed failure mainly occurred in groups P, PA, PS, and PPS. When load is applied to the adhesive interface, fracture occurs at the weaker of the adhesive force or cohesive force. Therefore, it was concluded that adhesive strength was low in groups C and A, in which there was primarily adhesive failure, and actually showed low shear bond strength. Therefore, it is believed that a lot of material fell off when the denture lining material was used without additional sur-face treatment on the 3D-printed dentures.

One limitation of this study was that the shear bond strength was measured without thermocycling or additional cyclic loading on the fabricated specimen. In the oral environment, saliva is present and a very humid environment is maintained; further, temperature change and occlusal load during food intake could not be reproduced.[44] Since the oral environment can affect the mechanical properties of dental polymers, thermocycling is considered essential and additional research is required on changes in bond strength between the 3D printing denture base and chairside reline resin according to the number of thermocycles. As another limitation, the shear bond strength is significantly affected by material properties such as the specimen geometry and elastic modulus compared to the tensile bond strength.[45] The shape of the specimen in this study did not reproduce the appearance of dentures, and the denture base material was DUDMA, which has high flexibility compared to that of PMMA, and therefore has a low modulus of elasticity.[10] This research was conducted using one type of denture base and relining material. The difference in modulus of elasticity between the DUDMA and PEMA was believed to affect shear bond strength. Further studies are needed to produce specimens that reflect the shape of dentures and to evaluate using various 3D printing resins and materials for relining. Moreover, studies to compare bond strength by selecting relining materials which have similar chemical structures with the denture base resin are also needed.

CONCLUSION

The following conclusions were obtained within these limitations. The Rocatec system group showed significantly higher shear bond strength between the 3D-printed denture base and the chairside relining material, than all other groups. The bond strength in the group where sandblasting or sandblasting with adhesive applied was lower than that of the group to which the Rocatec system was applied, but was significantly higher than the group to which no surface treatment or adhesive was applied ($P < .05$). As a result of failure mode analysis, the control and adhesive groups primarily exhibited adhesive failure, whereas

mainly mixed failure occurred in the other groups. It is believed that higher bond strength can be obtained by performing additional surface treatment in a clinical situation where there are restrictions to choose the denture base resin and hard relining material, and the Rocatec system was the most effective in this study.

REFERENCES

1. Al-Rafee MA. The epidemiology of edentulism and the associated factors: A literature review. J Family Med Prim Care 2020;9:1841-3.

2. Douglass CW, Shih A, Ostry L. Will there be a need for complete dentures in the United States in 2020? J Prosthet Dent 2002;87:5-8.

3. Saponaro PC, Yilmaz B, Heshmati RH, McGlumphy EA. Clinical performance of CAD-CAM-fabricated complete dentures: A cross-sectional study. J Prosthet Dent 2016;116:431-5.

4. Bidra AS, Taylor TD, Agar JR. Computer-aided technology for fabricating complete dentures: systematic review of historical background, current status, and future perspectives. J Prosthet Dent 2013;109:361-6.

5. Goodacre CJ, Garbacea A, Naylor WP, Daher T, Marchack CB, Lowry J. CAD/CAM fabricated complete dentures: concepts and clinical methods of obtaining required morphological data. J Prosthet Dent 2012;107:34-46.

6. Goodacre BJ, Goodacre CJ, Baba NZ, Kattadiyil MT. Comparison of denture base adaptation between CAD-CAM and conventional fabrication techniques. J Prosthet Dent 2016;116:249-56.

7. Kattadiyil MT, AlHelal A. An update on computer-engineered complete dentures: A systematic review on clinical outcomes. J Prosthet Dent 2017;117:478-85.

8. Infante L, Yilmaz B, McGlumphy E, Finger I. Fabricating complete dentures with CAD/CAM technology. J Prosthet Dent 2014;111:351-5.

9. Janeva NM, Kovacevska G, Elencevski S, Panchevska S, Mijoska A, Lazarevska B. Advantages of CAD/CAM versus conventional complete dentures - a review. Open Access Maced J Med Sci 2018;6:1498-502.

10. Lee DH, Lee JS. Comparison of flexural strength according to thickness between CAD/CAM denture base resins and conventional denture base resins. J Dent Rehabil Appl Sci 2020;36:183-95.

11. Azari A, Nikkad S. The evolution of rapid prototyping in dentistry: a review. Rapid Prototyp J 2009;15;216-25.

12. Alharbi N, Wismeijer D, Osman RB. Additive manufacturing techniques in prosthodontics: Where do we currently stand? A critical review. Int J Prosthodont 2017;30:474-84.

13. You SG, You SM, Kang SY, Bae SY, Kim JH. Evaluation of the adaptation of complete denture metal bases fabricated with dental CAD-CAM systems: An in vitro study. J Prosthet Dent 2021;125:479-85.

14. He Y, Wu Y, Fu J, Gao Q, Qiu J. Developments of 3D printing microfluidics and applications in chemistry and biology: a review. Electroanalysis 2016;28:1658-78.

15. Lee S. Prospect for 3D printing technology in medical, dental, and pediatric dental field. J Korean Acad Pediatr Dent 2016;43:93-108.

16. Tallgren A. The continuing reduction of the residual alveolar ridges in complete denture wearers: a mixed-longitudinal study covering 25 years. J Prosthet Dent 1972;27:120-32.

17. Christensen FT. Relining techniques for complete dentures. J Prosthet Dent 1971;26:373-81.

18. Leles CR, Machado AL, Vergani CE, Giampaolo ET, Pavarina AC. Bonding strength between a hard chairside reline resin and a denture base material as influenced by surface treatment. J Oral Rehabil 2001;28:1153-7.

19. Kim HS, Jung JH, Bae JM, Kim JM, Kim YL. Tensile bond strength of chairside reline resin to denture bases fabricated by sutractive and additive manufacturing. J Korean Acad Prosthodont 2020;58:177-84.

20. Awad AN, Cho SH, Kesterke MJ, Chen JH. Comparison of tensile bond strength of denture reline materials on denture bases fabricated with CAD-CAM technology. J Prosthet Dent. 2021 Aug 6:S0022-3913(21)00365-6.

21. al-Athel MS, Jagger RG. Effect of test method on the bond strength of a silicone resilient denture lining material. J Prosthet Dent 1996;76:535-40.

22. Choi JE, Ng TE, Leong CKY, Kim H, Li P, Waddell JN. Adhesive evaluation of three types of resilient denture liners bonded to heat-polymerized, autopolymerized, or CAD-CAM acrylic resin denture bases. J Prosthet Dent 2018;120:699-705.

23. Palitsch A, Hannig M, Ferger P, Balkenhol M. Bonding of acrylic denture teeth to MMA/PMMA and light-curing denture base materials: the role of conditioning liquids. J Dent 2012;40:210-21.

24. ISO 10139-2. Dentistry - Soft lining materials for removable dentures - Part 2: Materials for long-term use. International Standards Organization (ISO); Geneva; Switzerland, 2016.

25. Wemken G, Burkhardt F, Spies BC, Kleinvogel L, Adali U, Sterzenbach G, Beuer F, Wesemann C. Bond strength of conventional, subtractive, and additive manufactured denture bases to soft and hard relining materials. Dent Mater 2021;37:928-38.

26. Vallittu PK, Ruyter IE. Swelling of poly(methyl methacrylate) resin at the repair joint. Int J Prosthodont 1997;10:254-8.

27. Vallittu PK, Ruyter IE, Nat R. The swelling phenomenon of acrylic resin polymer teeth at the interface with denture base polymers. J Prosthet Dent 1997;78:194-9.

28. Sarac YS, Sarac D, Kulunk T, Kulunk S. The effect of chemical surface treatments of different denture base resins on the shear bond strength of denture repair. J Prosthet Dent 2005;94:259-66.

29. Quaas AC, Yang B, Kern M. Panavia F 2.0 bonding to contaminated zirconia ceramic after different cleaning procedures. Dent Mater 2007;23:506-12.

30. Li P, Krämer-Fernandez P, Klink A, Xu Y, Spintzyk S. Repairability of a 3D printed denture base polymer: Effects of surface treatment and artificial aging on the shear bond strength. J Mech Behav Biomed Mater 2021;114:104227.

31. Lim NK, Shin SY. Bonding of conventional provisional resin to 3D printed resin: the role of surface treatments and type of repair resins. J Adv Prosthodont 2020;12:322-8.

32. Papacchini F, Magni E, Radovic I, Mazzitelli C, Monticellia F, Goracci C, Polimeni A, Ferrari M. Effect of intermediate agents and pre-heating of repairing resin on composite-repair bonds. Oper Dent 2007;32:363-71.

33. Zhang H, Fang J, Hu Z, Ma J, Han Y, Bian J. Effect of oxygen plasma treatment on the bonding of a soft liner to an acrylic resin denture material. Dent Mater J 2010;29:398-402.

34. Akin H, Tugut F, Mutaf B, Guney U, Ozdemir AK. Effect of sandblasting with different size of aluminum oxide particles on tensile bond strength of resilient liner to denture base. Cumhuriyet Dent J 2011;14:5-11.

35. Debnath S, Wunder SL, McCool JI, Baran GR. Silane treatment effects on glass/resin interfacial shear strengths. Dent Mater 2003;19:441-8.

36. Jeong KW, Kim SH. Influence of surface treatments and repair materials on the shear bond strength of CAD/CAM provisional restorations. J Adv Prosthodont 2019;11:95-104.

37. Bayati OH, Yunus N, Ahmad SF. Tensile bond strengths of silicone soft liners to two chemically different denture base resins. Int J Adhes 2012;34:32-7.

38. Choi E, Kwon EJ. Effects of treatment of silane coupling agent in MPS concentration on the shear bond strength between self curing resins and heat curing resin. J Korea Content Assoc 2015;15:344-51.

39. Kim YS, Woo YH, Lim HN, Choi BB. Stduy on the surface morphologe and shear bond strength of in-ceram core to resin cement after varing modes of surface conditioning. J Korean Acad Prosthodont 1995;33:693-704.

40. Heikkinen TT, Lassila LV, Matinlinna JP, Vallittu PK. Effect of operating air pressure on tribochemical silica-coating. Acta Odontol Scand 2007;65:241-8.

41. Park KS, Shin SY, Cho IH. Effects of surface treatments of the zirconium-based ceramic on the bond strength of resin cement. J Dent Rehabil Appl Sci 2006;22:221-30.

42. Kümbülo lu Ö, Yildirim B, Husain NA, Özcan M. Adhesion potential of relining materials to polyamide and PMMA-based denture base materials: effect of surface conditioning methods. J Adhes Sci Technol 2019;33:1939-47.

43. Kern M, Thompson VP. Sandblasting and silica coating of a glass-infiltrated alumina ceramic: volume loss, morphology, and changes in the surface composition. J Prosthet Dent 1994;71:453-61.

44. Silva Cde S, Machado AL, Chaves Cde A, Pavarina AC, Vergani CE. Effect of thermal cycling on denture base and autopolymerizing reline resins. J Appl Oral Sci 2013;21:219-24.

45. Placido E, Meira JB, Lima RG, Muench A, de Souza RM, Ballester RY. Shear versus micro-shear bond strength test: a finite element stress analysis. Dent Mater 2007;23:1086-92.