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Effect of surface treatment and luting agent type on shear bond strength of titanium to ceramic materials

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PURPOSE. This study aimed to compare the effect of different surface treatments and luting agent types on the shear bond strength of two ceramics to commercially pure titanium (Cp Ti). **MATERIALS AND METHODS.** A total of 160 Cp Ti specimens were divided into 4 subgroups (n = 40) according to surface treatments received (control, 50 µm airborne-particle abrasion, 110 µm airborne-particle abrasion, and tribochemical coating). The cementation surfaces of titanium and all-ceramic specimens were treated with a universal primer. Two cubic all-ceramic discs (lithium disilicate ceramic (LDC) and zirconia-reinforced lithium silicate ceramic (ZLC)) were cemented to titanium using two types of resin-based luting agents: self-cure and dual-cure (n = 10). After cementation, all specimens were subjected to 5000 cycles of thermal aging. A shear bond strength (SBS) test was conducted, and the failure mode was determined using a scanning electron microscope. Data were analyzed using three-way ANOVA, and the Tukey-HSD test was used for post hoc comparisons ($P < .05$). **RESULTS.** Significant differences were found among the groups based on surface treatment, resin-based luting agent, and ceramic type ($P < .05$). Among the surface treatments, 50 µm air-abrasion showed the highest SBS, while the control group showed the lowest. SBS was higher for dual-cure resin-based luting agent than self-cure luting agent. ZLC showed better SBS values than LDC. **CONCLUSION.** The cementation of ZLC with dual-cure resin-based luting agent showed better bonding effectiveness to commercially pure titanium treated with 50 µm airborne-particle abrasion. [J Adv Prosthodont 2022;14:78-87]

KEYWORDS
Bond strength; Hybrid abutment; Lithium silicate; Resin-based luting agent; Surface treatment

INTRODUCTION

Implant-supported restorations have many proven properties, such as long-lasting use and esthetics, making them a viable treatment alternative

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to traditional fixed dental prostheses for single tooth replacement.[1,2] Nowadays, the expectations from implant restorations also include esthetic solutions that provide appropriate contour and natural relations between the peri-implant soft tissue and the restorative material.[3,4] Conventionally, an implant restoration is classified as cement-retained or screw-retained. Abutments connect implants to implant-supported prostheses and provide mechanical stability and esthetic results.[3] Cement-retained implant restorations can be produced using prefabricated abutments or castable custom abutments.[5] However, custom castable abutments in cement-retained restorations may also involve the risk of cement residue that can lead to peri-implantitis and eventual marginal bone loss, particularly around the peri-implant soft tissue due to deep placement of implants in anterior teeth.[6] Custom abutments made of commercially pure titanium are considered the gold standard in the literature due to biocompatibility, mechanical properties, and clinical success.[7,8] However, the reflection of the metallic color from both the gingiva and under the restoration in full ceramic restorations negatively affects the esthetics. All-ceramic abutments demonstrate tooth-like color and possible biological advantages, especially optimal esthetics in the anterior region.[5,9] The first introduced ceramic abutments consisted of a single piece of zirconium, but several reports showed fracture complications, as the connection areas entering the implant were made of zirconium.[10] Therefore, two-piece all-ceramic abutments are preferred in esthetic abutment systems. Two-piece systems consist of restorations that can be extraorally cemented to titanium bases, have full-contour anatomy, or be bonded to a custom-designed all-ceramic abutment material attached to a titanium base.[11] Two-piece esthetic abutments provide a titanium-titanium interface at the implant-abutment connection and show a higher fracture resistance than one-piece esthetic abutments, thus reducing the risk of implant platform damage under occlusal forces.[12] With the development of CAD-CAM technologies, custom esthetic abutments and ceramic restorations can be produced in one appointment with chairside CAD-CAM systems at economical costs.[13] Lithium disilicate ceramics are preferred options due to their esthetic properties for chairside 2-piece restorations in clinics.[11] A new material containing zirconium particles in its glassy matrix[14] with easier polishing due to smaller particle size than lithium disilicate ceramics[15] has been introduced to improve the mechanical properties of all-ceramic materials. Although these products can be fabricated in a single dental appointment using CAD-CAM systems, their bonding to titanium in implant restorations is unknown.

A successful long-term bonding of esthetic restorations to titanium bases in the oral environment is crucial for the longevity of restorations. Various cementation procedures or surface treatments are available for bonding titanium bases to esthetic materials. Therefore, this study aimed to examine the effects of different resin-based luting agent types and surface roughening processes on the shear bond strength of Grade V pure commercial titanium to 2 all-ceramic materials. The null hypothesis was that different combinations of ceramic materials, surface treatments, and resin-based luting agent types do not influence the bond strength of titanium base to ceramic material.

MATERIALS AND METHODS

The composition and manufacturers of the materials used in the study are shown in Table 1. A total of 160 disc-shaped Cp Ti (10 mm in diameter and 3 mm in height) (Premium 5030 CNC milling machine; Eiterfeld, Germany) were fabricated using the milling method and embedded in chemically polymerized acrylic resin (Meliodent; Heraeus Kulzer, South Bend, IN, USA). Discs were cleaned ultrasonically for 5 minutes and divided into four groups to receive surface treatments (n = 40). The first group of samples received no surface treatment and served as a control group. The second group received airborne-particle abrasion with 50 µm Al_2O_3 and the third group with 110 µm Al_2O_3 at 2 bar pressure for 10 s at an angle of 45 degrees. The fourth group received tribochemical coating with 30-µm silicatized Al_2O_3 particles (CoJet™ System; 3M ESPE, Seefeld, Germany) at 2 bar pressure for 15 seconds, as recommended by the manufacturer. After surface treatment, the samples were cleaned in an ultrasonic cleaner for 180 s with 10% alcohol. Each treated group was further divided into two subgroups

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Table 1. Types and compositions of the materials used in the study

Product	Composition	Type	Manufacturer
IPS e.max CAD	SiO_2 57.0-80.0%, Li_2O 11.0-19.0%, K_2O 0.0-13.0%, P_2O_5 0.0-11.0%, ZrO_2 0.0-8.0%, ZnO 0.0-8.0%, Colorants 0.0-18.0%	Lithium disilicate ceramic	Ivoclar Vivadent, Schaan, Liechtenstein
Celtra Duo	SiO_2 59.3%, Al_2O_3 3%, Li_2O 14.5%, K_2O 1.2%, Na_2O 0.2%, P_2O_5 4.9%, B_2O_3 2%, MgO 0.01%, ZrO_2 9.3%, SrO 0,0003%, CeO_2 0.83%, V_2O_5 0.61%, Tb_2O_3 3.3%, Er_2O_3 0.73%, HfO_2 0.21%	Zirconia reinforced lithium silicate ceramic	Dentsply Sirona, Hanau, Germany
Multilink Hybrid Abutment	Bisphenol A diglycidyl methacrylate ethoxylated (bis-EMA), urethane dimethacrylate (UDMA), 2-hydroxyelthyl methacrylate, ytterbium trifluoride, dibenzoyl peroxide	Self-cure resin-based luting agent	Ivoclar Vivadent, Schaan, Liechtenstein
Panavia V5	Bis-GMA, TEGDMA, hydrophobic aromatic dimethacrylate, hydrophilic aliphatic dimethacrylate, barium glass filler, fluoroaluminosilicate glass, silica filler, initiators, stabilizers, pigments	Dual-cure resin-based luting agent	Kuraray Noritake Dental, Tokyo, Japan

(n = 20) to receive all-ceramic specimens: (1) lithium disilicate ceramic (IPS e.max CAD; Ivoclar Vivadent AG, Schaan, Liechtenstein), (2) zirconia-reinforced lithium silicate ceramic (Celtra Duo; Dentsply Sirona, Konstanz, Germany). Ceramic specimens were milled from blocks (5 mm diameter, 3 mm height) and fired in a ceramic oven (Programat P310; Ivoclar Vivadent, Schaan, Liechtenstein), following the parameters provided by the manufacturers (e.max CAD: 403°C start, 90°C/min heating rate, 820°C final #1, 10:00 holding time #1, 840°C final #2, 7:00 holding time #2; Celtra Duo: 500°C start, 55°C/min heating rate, 820°C final, 1:30 holding time). Zirconia-reinforced lithium silicate restorations were etched using 4.8% hydrofluoric acid etching gel (IPS Ceramic Etching Gel; Ivoclar Vivadent, Schaan, Liechtenstein) for 30 s, lithium disilicate restorations were etched with the same etching gel for 20 seconds, and both were then rinsed with water spray. Ceramic specimens were divided into two groups, according to resin-based luting agent type: Multilink Hybrid Abutment (Ivoclar Vivadent, Schaan, Liechtenstein) and Panavia V5 (Kuraray Noritake Dental, Tokyo, Japan). Monobond Plus was applied to titanium and ceramic specimens, allowed to react for 60 s, and air-dried for the Multilink Hybrid Abutment resin-based luting agent group. For the Panavia V5 group, Clearfil Ceramic Primer Plus was applied to titanium and ceramic specimens and dried. Resin-based luting agents were applied to ceramic surfaces and cemented to the Ti surface under 15 N pressure with a Gillmore device. Specimens of the Panavia V5 resin-based luting agent group were light-cured for 5 seconds using a light-emitting diode (LED) light (VALO™ Cordless; Ultradent, South Jordan, UT, USA). Specimens of the Multilink Hybrid resin-based luting agent group were autopolymerized for 7 minutes. Excess luting material on the margins was removed using a scalpel. All cementation procedures were performed by the same operator (G.S.O).

All specimens were stored in a humidifier for 24 h at 37°C and aged by thermal cycling (5000 cycles, 5° - 55°C) with a dwell time of 20 s in distilled water. The bonded specimens were placed in a universal testing machine and loaded with a crosshead speed of 1 mm/min. The maximum shear load was recorded immediately before debonding. The following formula was used to calculate the SBS data: fracture load/bonding surface area = N/mm^2 = MPa. Failure types were examined using a reflected-light microscope (Olympus SZ40; Olympus Optical Co., Tokyo, Japan) at 20× magnification (Fig. 1). Failure types were determined according to the amount of luting material remaining on the titanium surface, from score 0 to 3, as indicated in a previous study where score 0 represents adhesive failure and score 3 is complete cohesive failure.[16]

We selected one specimen randomly from each sur-

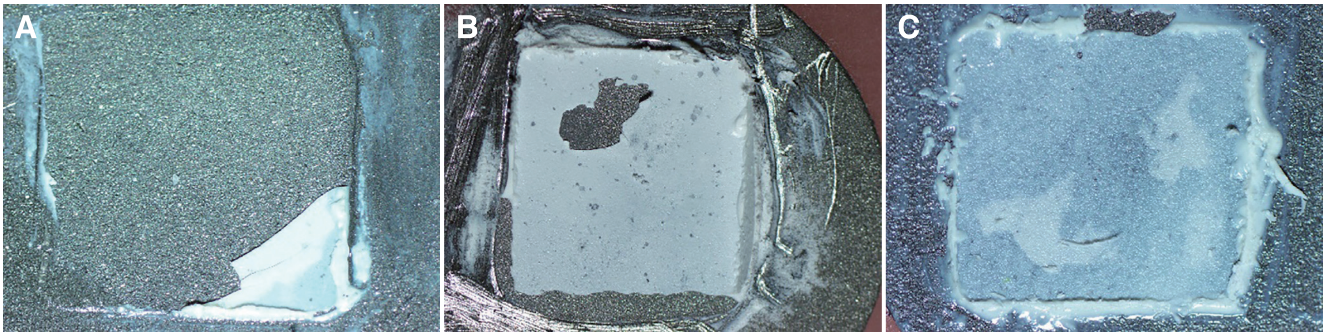

Fig. 1. Reflected-light microscope images after SBS test as score 1 (A), score 2 (B), score 3 (C).

face treatment group for SEM imaging. Selected specimens were cleaned ultrasonically in distilled water for 5 minutes, dried, and coated with a thin Au-Pd layer (200 - 300 nm). SEM (Zeiss Supra 40 VP; Carl Zeiss AG, Germany) was used for surface examination and results were presented as photographs.

Statistical analysis was performed using standard statistical software (SPSS V23; IBM Armonk, NY, USA). The Kolmogorov-Smirnov test (P > .05 for all tests) and Levene test (P = .437) confirmed that all the data were normally distributed and homogeneous; therefore, parametric tests were used. The effect of surface treatment, resin-based luting agent, and ceramic on shear bond strength was examined by a 3-way analysis of variance. The Bonferroni test was used to examine the main effects, while multiple comparisons were examined with the Tukey HSD test for interactions ($P \leq .05$).

RESULTS

The mean and standard deviation values of the SBS test from surface treatment, ceramic, and resin-based luting agent are shown in Table 2. The total values at the end of each column show the main effect of the surface treatments. The total values at the end of the Total line show the main effect of the ceramics. The main effect of the resin-based luting agent is seen when the total values at the end of the row and column are matched. Other total values show interactions. A 3-way ANOVA was performed to determine the main effects of surface treatment, resin-based

Table 2. The mean and standard deviation values of SBS test from surface treatment, ceramic and resin-based luting agent

Resin-based luting agent	Ceramic	Surface treatment				Total
		Control	50 µm airborne-particle abrasion	100 µm airborne-particle abrasion	Tribochemical silica coating	
Multilink Hybrid	e.max CAD	9.13 ± 0.91	15.89 ± 1.03	15.56 ± 1.46	12.89 ± 1.11	13.37 ± 2.95^{C}
	Celtra Duo	9.62 ± 0.94	20.67 ± 1.19	18.17 ± 3.34	12.68 ± 1.19	15.29 ± 4.79^{B}
	Total	9.38 ± 0.94^{D}	18.28 ± 2.68^{AB}	16.86 ± 2.84^{BC}	12.79 ± 1.12^{D}	14.33 ± 4.07
Panavia V5	e.max CAD	12.6 ± 1.62	17.58 ± 1.37	18.16 ± 1.3	15.43 ± 2.11	15.94 ± 2.71^{AB}
	Celtra Duo	12.71 ± 1.98	20.74 ± 2.29	17.38 ± 1.18	15.77 ± 2.43	16.65 ± 3.52^{A}
	Total	12.66 ± 1.76^{E}	19.16 ± 2.45^{A}	17.77 ± 1.28^{AB}	15.6 ± 2.22^{C}	16.3 ± 3.14
Total	e.max CAD	10.87 ± 2.19^{T}	16.73 ± 1.46^{Y}	16.86 ± 1.9^{Y}	14.16 ± 2.1^{Z}	14.65 ± 3.1
	Celtra Duo	11.17 ± 2.19^{T}	20.71 ± 1.78^{X}	17.77 ± 2.47^{Y}	14.23 ± 2.44^{Z}	15.97 ± 4.23
	Total	11.02 ± 2.17^{a}	18.72 ± 2.58^{b}	17.31 ± 2.22^{c}	14.19 ± 2.25^{d}	15.31 ± 3.76

$^{a-d}$: There is no difference among the surface treatments with the same letter, $^{A-E}$: There is no difference between surface treatment and resin based luting agent interactions with the same letter, $^{X-T}$: There is no difference between surface treatment and ceramic interactions with the same letter.

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luting agent type, and ceramic (Table 3). There was a statistical difference among all surface treatments, with the highest result obtained in the 50 µm airborne-particle abrasion group. Resin-based luting agent type was also statistically significant ($P < .001$). The mean value was 14.33 MPa in the Multilink Hybrid Abutment resin-based luting agent group and 16.3 MPa in the Panavia V5 group. The ceramic type was also significant ($P < .001$); the mean value was 14.65 MPa in the e.max CAD group and 15.97 MPa in the Celtra Duo group. Surface treatment and resin-based luting agent interaction were statistically significant ($P = .002$). The highest results were obtained in the 50 µm airborne-particle abrasion Panavia V5 cement interaction (19.16 ± 2.45), and the lowest results were obtained in the control group Multilink Hybrid Abutment resin-based luting agent interaction (9.38 ± 0.94). Surface treatment and ceramic interactions were also statistically significant ($P < .001$). The highest results were obtained in 50 µm airborne-particle abrasion with Celtra Duo interaction (20.71 ± 1.78) and the lowest results in Celtra Duo (11.17 ± 2.19) and e.max CAD (10.87 ± 2.19) ceramics of the control group. Resin-based luting agent and ceramic interactions were also statistically significant ($P = .027$). The highest results were obtained in the Panavia V5 resin-based luting agent with Celtra Duo interaction (16.65 ± 3.52), while the Multilink Hybrid Abutment resin-based luting agent with e.max CAD interaction showed the lowest results (13.37 ± 2.95). No differences were found between Panavia V5 resin-based luting agent with the e.max CAD group and Multilink Hybrid Abutment resin-based luting agent with Celtra Duo interactions. The observed failure types by surface treatment, resin-based luting agent, and ceramic type are shown in Figure 2. Adhesive failure type (combination of scores 0 and 1) was more common than cohesive failure (combination of scores 2 and 3).

The SEM images of the surface treatment groups are shown in Figure 3. The control group showed the smoothest surface and followed by silica coating. Airborne-particle abrasion groups showed more irregularities and pores than control and silica-coated groups.

DISCUSSION

This study aimed to test the combined effects of routinely used surface treatments, various resin-based luting agent types, and ceramic types on bonding to titanium. The null hypothesis was rejected as surface treatments, ceramics, and resin-based luting agent type significantly affected shear bond strengths.

Previous studies investigating titanium bonding to ceramics reported that mechanical treatments applied to titanium surfaces increase the titanium-ceramic connection.[17-20] Therefore, Al_2O_3 air abrasion and tribochemical coating were chosen for the rough-

Table 3. The effect of surface treatment, resin-based luting agent and ceramic on SBS

	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Surface treatment	1412.649	3	470.883	159.441	< .001	0.769
Resin-based luting agent	155.065	1	155.065	52.505	< .001	0.267
Ceramic	69.055	1	69.055	23.382	< .001	0.140
Surface treatment × Resin-based luting agent	47.426	3	15.809	5.353	.002	0.100
Surface treatment × Ceramic	98.188	3	32.729	11.082	< .001	0.188
Resin-based luting agent × Ceramic	14.673	1	14.673	4.968	.027	0.033
Surface treatment × Resin-based luting agent × Ceramic	21.600	3	7.200	2.438	.067	0.048

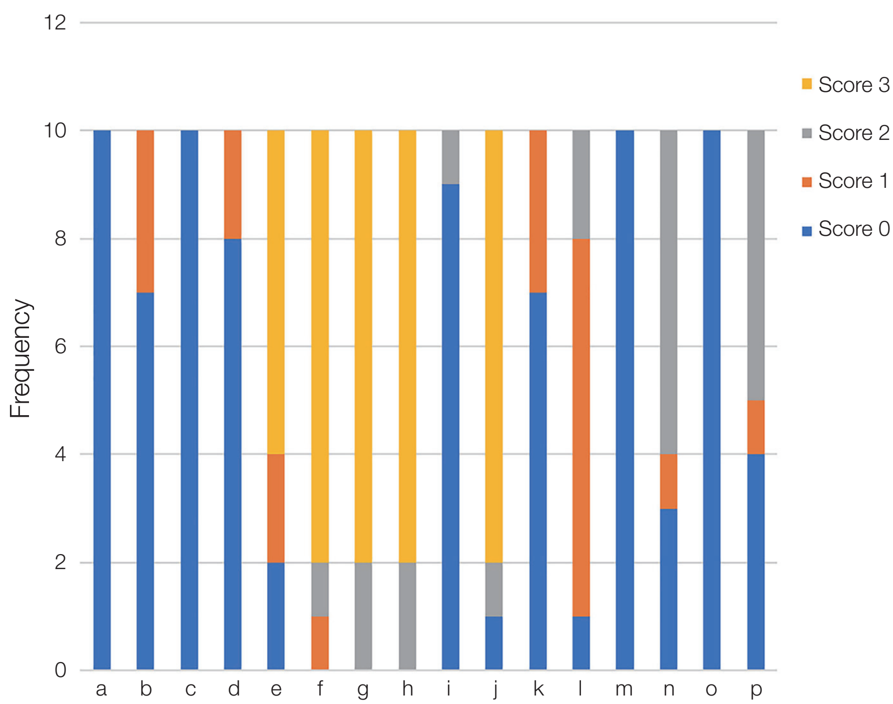

Fig. 2. Failure types of specimens.
a: Control + e.max CAD + Multilink Hybrid, b: Control + e.max CAD + Panavia V5, c: Control + Celtra Duo + Multilink Hybrid, d: Control + Celtra Duo + Panavia V5, e: 50 µm airborne-particle abrasion + e.max CAD + Multilink Hybrid, f: 50 µm airborne-particle abrasion + e.max CAD + Panavia V5, g: 50 µm airborne-particle abrasion + Celtra Duo + Multilink Hybrid, h: 50 µm airborne-particle abrasion + Celtra Duo + Panavia V5, i: 110 µm airborne-particle abrasion + e.max CAD + Multilink Hybrid, j: 110 µm airborne-particle abrasion + e.max CAD + Panavia V5, k: 110 µm airborne-particle abrasion + Celtra Duo + Multilink Hybrid, l: 110 µm airborne-particle abrasion + Celtra Duo + Panavia V5, m: Cojet + e.max CAD + Multilink Hybrid, n: Cojet + e.max CAD + Panavia V5, o: Cojet + Celtra Duo + Multilink Hybrid, p: Cojet + Celtra Duo + Panavia V5.

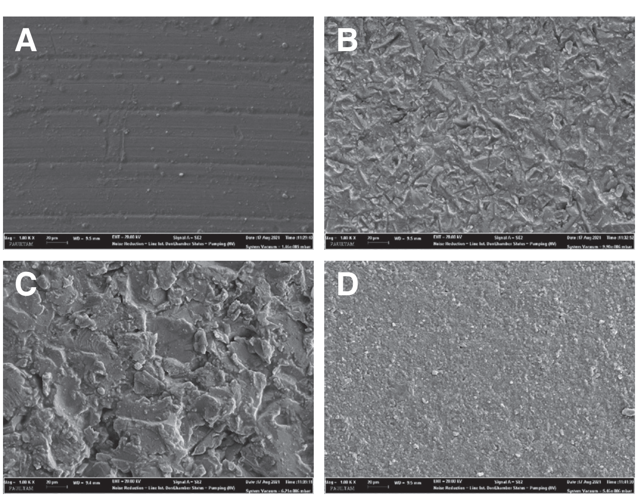

Fig. 3. SEM images of surface treatments as control (A), 50 µm airborne-particle abrasion (B), 110 µm airborne-particle abrasion (C) and silica coating (D). 1000× magnification.

ening of titanium as they can be applied in dental clinics and small laboratories. The group that did not receive any surface treatment served as a control.

Examination of the partial eta squared results showed that surface treatment mainly affects bonding. Each of the surface roughening methods increased the bond strength of ceramics to titanium surfaces. The results of the present study are consistent with previous studies using shear or tensile tests that reported the positive effect of airborne particle abrasion application on bond strength to titanium before silane or adhesive primer application.[21-24] Airborne-particle abrasion with 110 µm Al_2O_3 created more surface irregularities than airborne-particle abrasion with 50 µm Al_2O_3 in this study. However, this group showed lower bond strength than 50 µm Al_2O_3.

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For the titanium surfaces treated with airborne-particle abrasion, two factors that need consideration are roughness and surface composition. Fonseca *et al*.[23] found that Cp Ti abraded with 50 µm Al_2O_3 and treated with adhesive showed higher bond strength than 120 µm Al_2O_3 abraded groups. They discussed this result with the effect of surface composition changes after airborne-particle abrasion. For the present study, higher results in 50 µm Al_2O_3 groups could be due to changes in surface composition. Silica coating has also been reported for improving bonding to titanium due to a chemical reaction between the silica layer and silane.[22,25] However, similar to previous studies,[17,19] the present study found no significant increase in bond strength after tribochemical silica coating. In order to ensure standardization in the present study, the Cojet system was used at the same pressure as airborne-particle abrasion. As described in previous studies, the manufacturers of the Cojet system claim that 2 bar is the minimum accepted pressure for creating sufficient energy to embed the silica particles into the substrate. It can be concluded that higher pressure can generate more energy and better bonding results. On the other hand, chemical silica-silane bonding could have decreased by thermal aging applied in this study. However, SEM images showed that the silica coating did not produce as much surface roughness as airborne-particle abrasion.

Surface treatment and ceramic selection are more critical than surface treatment and resin-based luting agent selection in titanium-ceramic bonding according to partial eta squared results. In the present study, surface preparation and cementation procedures were applied according to the recommendations of manufacturers. For this reason, hydrofluoric acid etching gel at the same concentrations (4.8%) was applied at different times. Fabian Fonzar *et al*.[25] compared the shear bond strength of lithium disilicate and zirconia-reinforced lithium silicate ceramics using different concentrations of hydrofluoric acid and different etching times. They found higher bonding results with the zirconia-reinforced lithium silicate group in the 4.9% hydrofluoric acid concentration and indicated that etching time did not significantly affect adhesion. In the present study, Monobond Plus was applied to the Multilink Hybrid resin-based luting agent group and Clearfil Ceramic Primer Plus to the Panavia V5 resin-based luting agent group; these primers contain 10-methacryloyloxydecyl dihydrogen phosphate (MDP) for chemical bonding between the resin-based luting agent and the metal. Monobond Plus and Clearfil Ceramic Primer Plus contain silane (trimethylpropyl methacrylate and 3-Methacryloxpropyl trimethoxysilane, respectively) and ethanol as solvent. Several studies in the literature have evaluated the comparative effect of Monobond Plus and Clearfil Ceramic Primer Plus to Alloy Primer on bonding.[17,26-29] Kemarly *et al*.[17] used Monobond Plus and Alloy Primer with different surface treatments on titanium abutment base and investigated the pull-off bond strength of a lithium disilicate abutment coping. They found better results with Monobond Plus and reported that the silane content of Monobond Plus could produce better bonding. On the other hand, in contrast with the present study, Freifrau von Maltzahn *et al*.[28] found better results with Monobond Plus than Clearfil Ceramic Primer Plus and Alloy Primer. However, applying Clearfil Ceramic Primer Plus only to ceramic surfaces and alloy primer to titanium surfaces may cause this difference in results. A previous study by the same researchers showed better results in specimens with Ceramic Primer Plus applied to titanium and ceramic surfaces than other groups.[27] Various studies evaluating the bond strength of resin-based luting agents to titanium are available in the literature.[16,20,29-33] However, different results emerged even in the studies using similar luting agent types. These differences could be due to the primers used, specimen differences in study design, or compositional differences in luting agents, including different ratios of monomers and chemical/light catalysts. According to ISO 9693:2019, the bond strength between metal-ceramic systems for dental restorations should be above 25 MPa, and in the present study, none of the groups could reach this value.[34] It is noteworthy that this value is for veneering porcelains on metal substrates only. However, according to ISO 10477, the minimum acceptable SBS value for resin-based materials to different substrates is 5 MPa,[35] and clinically, the resin-metal interface should be at least 10 MPa for satisfactory results.[36] In the present study, all bonding values were above 10 MPa in surface-treated groups, even close to this value in the control group. Thus, it can be considered that both luting agents provided adequate clinical bonding. Dhesi *et al*.[16] investigated the shear bond strength of lithium disilicate (e.max CAD) and four other ceramics to titanium with different luting agent types, including self-etch dual-cure resin and self-cure (Multilink Hybrid) resin-based luting agent in their study. Similar to the present study, they reported higher bond strengths with dual-cure resin-based luting agent than self-cure resin-based luting agent for the lithium disilicate group. On the other hand, Pitta *et al*. published a case report describing a bonding failure in a full contour zirconia crown cemented with Multilink Hybrid resin-based luting agent on a titanium base. In the cementation of the subsequently reconstructed crowns, the titanium bases were air abraded and bonded with glass ionomer luting agent, and no loss of cementation was observed in the 1-year clinical follow-up. However, in this study, it was not stated whether any surface treatment was applied to the first restorations and titanium bases. It is therefore unclear whether the debonding is solely dependent on the bonding agent.[37] Failure modes after the shear bond test revealed a predominantly mixed cement distribution between Ti-base and ceramic surfaces for the airborne-particle abraded specimens. In contrast, all of the specimens showed adhesive failure in both luting agent groups of the control group. A systematic review and meta-analysis study reported that after the recommended surface treatment method (hydrofluoric acid etching and silanization) application, no significant difference was found in the bond strengths of lithium disilicate and zirconia-reinforced lithium silicate to resin-based luting agents.[38] These observations support the benefit of airborne-particle abrasion to improve the adhesion to titanium surfaces and may explain the adhesive failure between the titanium and the cement in the untreated control group and the successful bonding between the resin-based luting agent and the ceramic.

In the present study, flat specimen surfaces were used for the bonding test. However, crown taper, crown height, and Ti base could affect retention. Due to this limitation, further studies should evaluate different ceramic and resin-based luting agent types with more retentive forms.

CONCLUSION

The shear bond test showed that the highest bond strength occurred with 50 µm Al_2O_3 abrasion. Among the ceramic materials studied herein, the zirconia-reinforced lithium silicate ceramic group showed higher bond strength than the lithium disilicate ceramic group. Dual-cure resin-based luting agent provided higher bond strength between titanium surface and ceramic than self-cure resin-based luting agent.

REFERENCES

1. den Hartog L, Slater JJ, Vissink A, Meijer HJ, Raghoebar GM. Treatment outcome of immediate, early and conventional single-tooth implants in the aesthetic zone: a systematic review to survival, bone level, soft-tissue, aesthetics and patient satisfaction. J Clin Periodontol 2008;35:1073-86.
2. Pjetursson BE, Tan K, Lang NP, Brägger U, Egger M, Zwahlen M. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years. Clin Oral Implants Res. 2004;15:625-42.
3. Gehrke P, Johannson D, Fischer C, Stawarczyk B, Beuer F. In vitro fatigue and fracture resistance of one- and two-piece CAD-CAM zirconia implant abutments. Int J Oral Maxillofac Implants 2015;30:546-54.
4. Elsayed A, Wille S, Al-Akhali M, Kern M. Effect of fatigue loading on the fracture strength and failure mode of lithium disilicate and zirconia implant abutments. Clin Oral Implants Res 2018;29:20-7.
5. Sailer I, Zembic A, Jung RE, Hämmerle CH, Mattiola A. Single-tooth implant reconstructions: esthetic factors influencing the decision between titanium and zirconia abutments in anterior regions. Eur J Esthet Dent 2007;2:296-310.
6. Wadhwani C, Rapoport D, La Rosa S, Hess T, Kretschmar S. Radiographic detection and characteristic patterns of residual excess cement associated with cement-retained implant restorations: a clinical report. J Prosthet Dent 2012;107:151-7.
7. Marchack CB. A custom titanium abutment for the anterior single-tooth implant. J Prosthet Dent 1996;76:

288-91.
8. Sailer I, Philipp A, Zembic A, Pjetursson BE, Hämmerle CH, Zwahlen M. A systematic review of the performance of ceramic and metal implant abutments supporting fixed implant reconstructions. Clin Oral Implants Res 2009;20:4-31.
9. Jung RE, Sailer I, Hämmerle CH, Attin T, Schmidlin P. In vitro color changes of soft tissues caused by restorative materials. Int J Periodontics Restorative Dent 2007;27:251-7.
10. Alsahhaf A, Spies BC, Vach K, Kohal RJ. Fracture resistance of zirconia-based implant abutments after artificial long-term aging. J Mech Behav Biomed Mater 2017;66:224-32.
11. Lin WS, Harris BT, Zandinejad A, Martin WC, Morton D. Use of prefabricated titanium abutments and customized anatomic lithium disilicate structures for cement-retained implant restorations in the esthetic zone. J Prosthet Dent 2014;111:181-5.
12. Foong JK, Judge RB, Palamara JE, Swain MV. Fracture resistance of titanium and zirconia abutments: an in vitro study. J Prosthet Dent 2013;109:304-12.
13. Conejo J, Kobayashi T, Anadioti E, Blatz MB. Performance of CAD-CAM monolithic ceramic implant-supported restorations bonded to titanium inserts: A systematic review. Eur J Oral Implantol 2017;10:139-46.
14. Abdulkader KF, Elnaggar GAE, Kheiralla LS. Shear bond strength of cemented zirconia-reinforced lithium silicate ceramics (Celtra Duo) with two surface treatments (in vitro study). J Adhes Sci Technol 2021;35:35-51.
15. Abdalla MM, Ali IAA, Khan K, Mattheos N, Murbay S, Matinlinna JP, Neelakantan P. The influence of surface roughening and polishing on microbial biofilm development on different ceramic materials. J Prosthodont 2021;30:447-53.
16. Dhesi GS, Sidhu S, Al-Haj Husain N, Özcan M. Evaluation of adhesion protocol for titanium base abutments to different ceramic and hybrid materials. Eur J Prosthodont Restor Dent 2021;29:22-34.
17. Kemarly K, Arnason SC, Parke A, Lien W, Vandewalle KS. Effect of various surface treatments on Ti-base coping retention. Oper Dent 2020;45:426-34.
18. Guilherme N, Wadhwani C, Zheng C, Chung KH. Effect of surface treatments on titanium alloy bonding to lithium disilicate glass-ceramics. J Prosthet Dent 2016;116:797-802.
19. Pitta J, Burkhardt F, Mekki M, Fehmer V, Mojon P, Sailer I. Effect of airborne-particle abrasion of a titanium base abutment on the stability of the bonded interface and retention forces of crowns after artificial aging. J Prosthet Dent 2021;126:214-21.
20. Alkhadashi A, Güven MÇ, Erol F, Yıldırım G. The effect of different combinations of surface treatments and bonding agents on the shear bond strength between titanium alloy and lithium disilicate glass-ceramic. Int J Periodontics Restorative Dent 2020;40:271-6.
21. de Almeida-Júnior AA, Fonseca RG, Haneda IG, Abi-Rached Fde O, Adabo GL. Effect of surface treatments on the bond strength of a resin cement to commercially pure titanium. Braz Dent J 2010;21:111-6.
22. Abi-Rached Fde O, Fonseca RG, Haneda IG, de Almeida-Júnior AA, Adabo GL. The effect of different surface treatments on the shear bond strength of luting cements to titanium. J Prosthet Dent 2012;108:370-6.
23. Fonseca RG, Haneda IG, Almeida-Júnior AA, de Oliveira Abi-Rached F, Adabo GL. Efficacy of air-abrasion technique and additional surface treatment at titanium/resin cement interface. J Adhes Dent 2012;14:453-9.
24. Elsaka SE, Swain MV. Effect of surface treatments on the adhesion of self-adhesive resin cements to titanium. J Adhes Dent 2013;15:65-71.
25. Fabian Fonzar R, Goracci C, Carrabba M, Louca C, Ferrari M, Vichi A. Influence of acid concentration and etching time on composite cement adhesion to lithium-silicate glass ceramics. J Adhes Dent 2020;22:175-82.
26. Matinlinna JP, Lassila LV, Vallittu PK. Evaluation of five dental silanes on bonding a luting cement onto silica-coated titanium. J Dent 2006;34:721-6.
27. Cardenas AM, Siqueira F, Hass V, Malaquias P, Gutierrez MF, Reis A, Perdigão J, Loguercio A. Effect of MDP-containing silane and adhesive used alone or in combination on the long-term bond strength and chemical interaction with lithium disilicate ceramics. J Adhes Dent 2017;19:203-12.
28. von Maltzahn NF, Holstermann J, Kohorst P. Retention forces between titanium and zirconia components of two-part implant abutments with different techniques of surface modification. Clin Implant Dent Relat Res 2016;18:735-44.

29. Freifrau von Maltzahn N, Bernard S, Kohorst P. Two-part implant abutments with titanium and ceramic components: Surface modification affects retention forces-An in-vitro study. Clin Oral Implants Res 2019;30:903-9.
30. Nakhaei M, Fendereski Z, Alavi S, Mohammadipour HS. The Micro-Shear bond strength of different cements to commercially pure titanium. J Clin Exp Dent 2019;11:e820-8.
31. Linkevicius T, Caplikas A, Dumbryte I, Linkeviciene L, Svediene O. Retention of zirconia copings over smooth and airborne-particle-abraded titanium bases with different resin cements. J Prosthet Dent 2019; 121:949-54.
32. Mehl C, Zhang Q, Lehmann F, Kern M. Retention of zirconia on titanium in two-piece abutments with self-adhesive resin cements. J Prosthet Dent 2018; 120:214-9.
33. Bankoğlu Güngör M, Karakoca Nemli S. The effect of resin cement type and thermomechanical aging on the retentive strength of custom zirconia abutments bonded to titanium inserts. Int J Oral Maxillofac Implants 2018;33:523-9.
34. ISO 9693. Metal-ceramic dental restorative systems. International Standards Organization (ISO); Geneva; Switzerland, 1999. Available at: https://www.iso.org/standard/23716.html
35. ISO 10477. Dentistry - Polymer-based crown and veneering materials. International Standards Organization (ISO); Geneva; Switzerland, 2018. Available at: https://www.iso.org/standard/68235.html
36. Matsumura H, Yanagida H, Tanoue N, Atsuta M, Shimoe S. Shear bond strength of resin composite veneering material to gold alloy with varying metal surface preparations. J Prosthet Dent 2001;86:315-9.
37. Pitta J, Todorovic A, Fehmer V, Strasding M, Sailer I. Technical complication of a zirconia multiple-unit FDP supported by titanium base abutments - case report on a bonding failure and treatment alternative. Int J Prosthodont 2021;34:518-27.
38. Zhang LX, Hong DW, Zheng M, Yu H. Is the bond strength of zirconia-reinforced lithium silicate lower than that of lithium disilicate? A systematic review and metaanalysis. J Prosthodont Res 2021 Dec 1. Epub ahead of print.