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Adhesion of Orthodontic Braces to Different Restorative Materials: Influence of Surface Conditioning Methods

Ortodontik Braketlerin Farklı Restoratif Materyallere Adezyonu: Yüzey İşleme Yöntemlerinin Etkisi

Rana TURUNÇ-OĞUZMAN[1]
Soner ŞİŞMANOĞLU[2,3]

[1]Department of Prosthodontics, Faculty of Dentistry, Altınbaş University, İstanbul, Turkey
[2]Department of Restorative Dentistry, Faculty of Dentistry, Altınbaş University, İstanbul, Turkey
[3]Department of Restorative Dentistry, Faculty of Dentistry, İstanbul University-Cerrahpaşa, İstanbul, Turkey

ABSTRACT

Objective: The purpose of this study was to analyze the shear bond strength of orthodontic metal braces to restorative materials with various constituents and manufacturing methods after different surface conditioning methods.

Methods: The samples were prepared from Vita Mark II, Shofu Block HC, Brilliant Crios computer-aided design/computer-aided manufacturing blocks, and Gradia Direct composite restorative material, and they were exposed to 5000 thermal cycles. Fabricated samples were divided into 6 groups based on the surface conditioning method (n = 12): control (no conditioning); etching with hydrofluoric acid; sandblasting with aluminum oxide; tribochemical silica coating with CoJet sand; bur abrasion; Monobond Etch and Prime application. The surface characteristics of the restorative materials were analyzed with a scanning electron microscope. The universal adhesive was applied to the specimens, and orthodontic braces were bonded with a light-cure adhesive paste. After thermal cycling, shear bond strength values were measured, and the adhesive remnant index was recorded. Two-way analysis of variance and Tukey tests were used for statistical analysis.

Results: Both the surface conditioning method and the material type significantly affected shear bond strength values. In addition, the interaction between these variables was significant ($P < .001$). Control groups of all restorative materials had significantly the lowest shear bond strength values.

Conclusion: Surface conditioning methods significantly enhanced the shear bond strength. Control groups of Vita Mark II and Shofu Block HC demonstrated shear bond strength values lower than the acceptable limit, but the rest of the groups showed adequate adhesion (above 6 MPa). Consequently, clinicians can prefer Monobond Etch and Prime along with a universal adhesive as a safer surface conditioning method.

Keywords: Bond strength, CAD/CAM, orthodontic braces, restorative materials, surface conditioning

ÖZ

Amaç: Bu çalışmanın amacı, ortodontik metal braketlerin çeşitli bileşenlere ve üretim süreçlerine sahip restoratif materyallere makaslama bağlanma direncini (MBD) farklı yüzey işlemleri sonrası analiz etmektir.

Yöntemler: Örnekler Vita Mark II, Shofu Block HC, Brilliant Crios CAD/CAM blokları ve Gradia Direct kompozit restoratif materyalinden hazırlanmıştır ve 5000 termal siklusa maruz bırakılmıştır. Hazırlanan örnekler, yüzey işleme yöntemine göre altı gruba ayrılmıştır (n = 12): kontrol (işlem yok); hidroflorik asit uygulaması; alüminyum oksit ile kumlama; CoJet kumu ile tribokimyasal silika kaplama; frez ile aşındırma; Monobond Etch and Prime (MEP) uygulaması. Restoratif materyallerin yüzey özellikleri taramalı elektron mikroskobu ile analiz edilmiştir. Örneklere üniversal adeziv uygulanmıştır ve ortodontik braketler ışıkla sertleşen adeziv pasta ile yapıştırılmıştır. Termal döngü sonrasında MBD değerleri ölçülmüştür ve artık adeziv indeksi kaydedilmiştir. İstatistiksel analiz için iki yönlü ANOVA ve Tukey testleri kullanılmıştır.

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Corresponding Author/Sorumlu Yazar: Rana TURUNÇ-OĞUZMAN
E-mail: ranaturunc@gmail.com

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Bulgular: Hem yüzey işleme yöntemi hem de malzeme türü MBD değerlerini anlamlı derecede etkilemiştir. Ayrıca, bu değişkenler arasındaki etkileşim de anlamlı bulunmuştur ($P < .001$). Tüm restoratif materyallerin kontrol gruplarının anlamlı derecede en düşük MBD değerlerine sahip olduğu görülmüştür.

Sonuç: Yüzey işleme yöntemleri MBD'yi anlamlı derecede arttırmıştır. Vita Mark II ve Shofu Block HC'nin kontrol gruplarının MBD değerlerinin kabul edilebilir sınırın altında olduğu tespit edilmiştir, fakat grupların geri kalanı yeterli adezyon (6 MPa'ın üzerinde) göstermiştir. Sonuç olarak, klinisyenler daha güvenli bir yüzey işleme yöntemi olan üniversal adeziv ile birlikte MEP kullanınımını tercih edebilirler.

Anahtar Kelimeler: bağlanma dayanımı, CAD/CAM, ortodontik braketler, restoratif materyaller, yüzey işlemi

INTRODUCTION

Adult patients seeking orthodontic treatment increase day by day owing to the advancements in orthodontic treatment options and the increase in aesthetic demands.[1] According to a recent study adult patients with age ranging between 19 and 40 constitute 51.3% of orthodontic patients.[2] In optimal conditions, orthodontic brackets are usually bonded to healthy tooth surfaces. However, an increase in the prevalence of direct and indirect restorations is observed in the adult population because of the predisposing malocclusion and other factors related to aging.[3] The problem related to these restorations is that bonding braces to them with enough strength remains as a question mark since there are various types of restorative materials.

Over the last 2 decades, the use of dental computer-aided design/computer-aided manufacturing (CAD/CAM) systems became more common due to their advantages such as accuracy, speed, precision, and optimization of human errors. Due to these advantages, manufacturers are focused on developing tooth-colored CAD/CAM restorative materials with improved mechanical and aesthetic properties.[4] First, the feldspathic ceramic CAD/CAM block that is highly aesthetic with good strength is introduced, but it had some disadvantages such as chipping, wearing the antagonist teeth, the requirement of firing, and challenge in occlusal adjustment and repair.[5,6] Resin-matrix ceramic CAD/CAM blocks combining the resin composites and dental ceramics are produced to overcome known disadvantages of the felspathic ceramic CAD/CAM blocks. Additionally, resin-matrix ceramic CAD/CAM materials have the advantages of resin composites, including higher flexibility and easy and fast fabrication processes with better marginal adaptation.[7,8]

The bond strength between orthodontic braces and restorative materials is important since brace failure is a common problem encountered in dental clinics. Each brace failure prolongs the duration of treatment for almost 18 days due to relapse in tooth movements, increases the number of appointments, and causes discomfort for the patient.[9,10] For these reasons, it is critical to sustain enough bond strength between the orthodontic brace and the restorative material until the end of treatment. Therefore, as different restorative materials require different surface treatments to increase bond strength, various surface conditioning methods were proposed which can be classified as chemical or mechanical.[11,12] As chemical methods, hydrofluoric acid, silane, and bonding agents can be applied.[12] Hydrofluoric acid is applied especially on ceramics to make a porous surface by dissolving the glassy component and thereby maintaining a favorable surface for bonding. However, it requires a very careful application process since it can cause irritation or necrosis on soft tissue, in direct contact.[13] Silane application after hydrofluoric acid etching is reported to be the most reliable surface conditioning method for increasing bond strength of dental ceramics, but during the debonding process, dental ceramics might be damaged.[14] Another chemical surface preparation method is the application of bonding agents and universal adhesives are the most recent with the ease of use and reliable bond strength to different restorative materials such as composite resin, ceramic, and zirconia.[14] As mechanical methods, sandblasting with aluminum oxide, tribochemical silica coating, or bur abrasion can be preferred as the organic component of the restorative material increases.[15] However, in repeated exposure, aluminum oxide and tribochemical silica coating may cause side effects on the respiratory tract and lungs, respectively.[16] Furthermore, sandblasting with aluminum oxide or abrading with a diamond bur may cause the production of heat and stress resulting in chipping or cracking of the restoration.[17]

Because of the need for a simpler and non-destructive method, manufacturers produced a new self-etching ceramic primer, Monobond Etch and Prime (MEP; Ivoclar Vivadent AG, Schaan, Liechtenstein). This chemical surface conditioner contains ammonium polyfluoride and trimethoxypropyl methacrylate providing gentle etching and simultaneous silanization, respectively.[18] There are few studies about MEP's efficiency in the adhesion of orthodontic braces to restorative materials.[19-21] However, the bonding performance of orthodontic metal braces to resin matrix ceramics with the application of MEP along with a universal adhesive is not clarified. Since the bond strength of orthodontic braces adhered to the restorative material depends directly on the material composition, which the clinicians cannot be sure of through intra-oral examination, there is a requirement to define a suitable bonding protocol for all metal-free restorative materials, which can achieve enough bond strength to resist orthodontic forces with minimal damage to the surface of restorative material while debonding. Therefore, this study aimed to assess the influence of different surface conditioning methods along with a universal adhesive on the shear bond strength (SBS) of orthodontic metal braces to various restorative materials. The null hypotheses were that (i) restorative material does not affect the SBS and (ii) the surface conditioning method along with a universal adhesive does not influence the SBS.

MATERIAL AND METHODS

Specimens were prepared from four different restorative materials, including a feldspathic ceramic (Vita Mark II; Vita Zahnfabrik H. Rauter, Bad Sackingen, Germany), a hybrid ceramic (Shofu Block HC; Shofu Dental GmbH, Ratingen, Germany), a reinforced

Table 1. Materials Used in the Study

Material	Type	Composition	Manufacturer	Lot no.
Vita Mark II	Feldspar ceramic	Fine-particle feldspar ceramic.	Vita Zahnfabrik H. Rauter, Bad Sackingen, Germany	35360
Shofu Block HC	Hybrid ceramic	UDMA, TEGDMA. Filler: Silica powder, micro-fumed silica, zirconium silicate, 61% by weight.	Shofu Dental GmbH, Ratingen, Germany	111501
Brilliant Crios	Reinforced composite	Cross-linked methacrylates (Bis-GMA, Bis-EMA, TEGDMA). Filler: Barium glass, and silica particles, 71% by weight.	Coltène, Altstätten, Switzerland	J00659
Gradia Direct	Light-cured micro-filled hybrid resin composite	UDMA, multifunctional methacrylate. Filler: Silica, prepolymerized fillers, fluoroalumino-silicate glass, 70% by weight.	GC Corporation, Tokyo, Japan	200327A

Bis-EMA, bisphenol A polyethylene glycol diether dimethacrylate; Bis-GMA, bisphenol A diglycidylmethacrylate; TGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

composite (Brilliant Crios; Coltène, Altstätten, Switzerland) CAD/CAM blocks, and a light-cured micro-filled hybrid resin composite (Gradia Direct; GC Corp., Tokyo, Japan) restorative material. Detailed information on the evaluated restorative materials is shown in Table 1.

According to the power analyses performed on G* Power software (version 3.1; University of Dusseldorf, Germany), the sample size was determined as 12 for each group, with a level of significance (α) of 0.05, power ($1-\beta$) of 0.80, and effect size (d) of 1.65, based on a previous study.[22] A sum of 72 samples, with a thickness of 2 mm, from each CAD/CAM block were fabricated with a micro-cutting machine (PRESI, Mecatome T180, France). In addition, 72 specimens of Gradia Direct composite resin were prepared in a square-shaped-silicone mold with a 10 width and 2 mm thickness. The composite resin was placed into the mold and covered with a glass plate to ensure a smooth, flat, and glossy surface. It was then light-cured for 40 seconds with an LED curing device (Elipar Deep Cure; 3M ESPE, St. Paul, Minn, USA). The thickness of each sample was checked with a digital caliper (Digimatic, Mitutoyo Co., Tokyo, Japan). Then the composite resin samples were kept in deionized water, at 37°C for 24 hours for the polymerization process to be completed. After that, all samples were implanted in a cold-cured acrylic resin (Vertex Dental, Zeist, Holland). The exposed surfaces of the specimens were ground finished with sandpapers of 600 to 1200-grit, along with water-cooling. The specimens were then cleaned in an ultrasonic bath filled with deionized water for 5 minutes and exposed to a thermocycling procedure (5000×, 5-55°C, dwell time of 30 seconds).[23,24] After thermocycling, specimens were randomly separated into 6 groups regarding the surface conditioning method (n = 12):

- Control: Surface conditioning was not applied.
- Hydrofluoric acid (HF): Hydrofluoric acid (9%; Ultradent, South Jordan, UT, USA) was applied to the specimens for 60 seconds.
- Sandblasting with aluminum oxide (AL): Samples were conditioned with aluminum-oxide by a sandblaster (Airsonic mini sandblaster; Hager Werken, Duisburg, Germany) from a 10 mm distance, with a pressure of 2 bar, for 10 seconds.
- Tribochemical silica coating with CoJet (CJ): Tribochemical silica coating was applied to the specimens, with CoJet grits (CoJet sand; 30 μm, 3M ESPE, Seefeld, Germany), using the same sandblaster with the same conditions.
- Bur abrasion (BUR): The samples were polished for 8 seconds using water-cooled 600-grit sandpaper since it simulates extra-fine diamond bur. [25,26]
- Monobond Etch and Prime: Sample surfaces were conditioned with MEP, regarding the manufacturer's instructions. Monobond Etch and Prime was rubbed on the samples with a micro brush for 20 seconds, left there for additional 40 seconds, and was washed off and dried with an air spray for 10 seconds.

All sample groups, excluding MEP, were washed off for 30 seconds with deionized water and dried with an oil-free air spray directly after surface conditioning to remove the remnants. Then a universal adhesive (Single Bond Universal; 3M ESPE) was rubbed with an applicator tip on each sample surface, for 20 seconds and gently air-dried for 5 seconds, then polymerized with an LED curing light (Elipar Deep Cure; 3M ESPE) for 10 seconds as instructed by the manufacturer. After that, lower central incisor braces (Mini Master Metal Brace; American Orthodontics, Sheboygan, Wis, USA) were adhered to the samples using a light-polymerizing adhesive paste (Transbond XT; 3M Unitek, Monrovia, Calif, USA). While bonding the braces, a firm finger pressure was performed to provide evenly distributed adhesive layer thickness. The excessive adhesive paste around the brace was removed with an explorer and discarded. Then adhesive paste was polymerized using the LED curing light for 40 seconds, 1 mm above the sample, from 2 directions to obtain sufficient polymerization. The light intensity of the LED curing light was checked periodically with a curing radiometer. Following the polymerization, samples were immersed in distilled water at 37°C for 24 hours. For standardization purpose, all procedure was accomplished by a single operator who was blinded to the study groups. Before the SBS test, the samples were again exposed to the same thermocycling procedure to simulate intra-oral conditions.

The SBS of the groups were analyzed with an SBS testing device (MOD Dental, Esetron Smart Robotechnologies, Ankara, Turkey) by applying shear force (N) to the adhesive interface with 0.5 mm/min crosshead speed. The SBS data were calculated in MPa, by the following equation: debonding force (N)/area of the brace base (9.34 mm^2). After debonding of braces, adhesive remnants on the restorative materials were observed under a stereomicroscope at a magnification of 40× and were categorized based on the adhesive remnant index (ARI) as follows: 1, 100% remnant; 2, ˃90% remnant; 3, 10%-90% remnant; 4, ˂10% remnant; 5, no remnant of adhesive paste remained on the restorative material.[27]

After surface conditioning methods were applied, the surface characteristics of two samples from each restorative material (a total of 12 samples) were examined using a scanning electron microscope (SEM) (Apreo S; Thermo Fisher Scientific, Waltham, MA, USA). Gold sputter coated (Polaron SC7620; ThermoVG Scientific, West Sussex, England) samples were analyzed at 10 kV accelerating voltage, with 1000× magnification.

Statistical Analysis

Statistical analysis was accomplished with software SPSS (Statistical Package for the Social Sciences) version 20.0 (IBM Corp.; Armonk, NY, USA). The data were analyzed through the Shapiro–Wilk and Kolmogorov–Smirnov tests to evaluate the normal distribution. A 2-way analysis of variance (ANOVA) test was conducted to assess the effect of restorative material type and surface conditioning method on SBS. For pairwise analyses, the

Table 2. Influence of Restorative Material Type and Surface Conditioning Method on SBS Results According to the 2-Way ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected model	3051.094[a]	23	132.656	32.081	.000***
Intercept	37 956.380	1	37 956.380	9179.232	.000***
Material	1763.945	5	352.789	85.317	.000***
Conditioning	615.318	3	205.106	49.602	.000***
Material * Conditioning	671.831	15	44.789	10.832	.000***
Error	893.166	216	4.135		
Total	41 900.640	240			
Corrected total	3944.260	239			

[a] R Squared = .774 (Adjusted R Squared = .749), *** $P < .001$.

Tukey honestly significant difference (HSD) test was performed ($\alpha = 0.05$ for all tests).

RESULTS

Based on the 2-way ANOVA test (Table 2), both the surface conditioning method and the material type significantly influenced the SBS values ($P < .001$). In addition, the interaction between these 2 variables was detected to be significant ($P < .001$).

The SBS values of the orthodontic braces to the restorative materials after different surface conditioning procedures are presented in Table 3. According to the pairwise analysis, among the control groups, Gradia Direct specimens exhibited significantly the highest SBS values. There was no significant difference between restorative materials for BUR, HF, and MEP conditioning groups. Among AL and CJ conditioned groups, Vita Mark II specimens showed significantly the lowest SBS values.

When the SBS values obtained for restorative materials are analyzed, it is observed that Vita Mark II specimens demonstrated significantly higher values in HF and MEP groups, followed respectively by BUR, AL, CJ, and control groups. Shear bond strength values demonstrated by Shofu Block HC were significantly higher in CJ, AL, MEP, and HF groups followed by BUR and control groups. When the surface conditioning methods, applied to Gradia Direct specimens are compared, it is observed that significantly lowest values were obtained for the control group followed by the MEP group. However, there was no significant difference among the other conditioning methods. Surface conditioning methods favor the SBS values of Brilliant Crios significantly; however, no significant difference among surface conditioning methods was detected.

As presented in Table 4, Gradia Direct specimens conditioned with BUR or AL and Brilliant Crios specimens conditioned with CJ or AL had the highest incidence of score 1 (90%), while Vita Mark II specimens conditioned with CJ or AL had the lowest incidence of score 1 (50%) among surface conditioned groups. Control groups of Vita Mark II and Shofu Block HC have shown exclusively score 5 ARI score, and Brilliant Crios has shown a 90% score 5 ARI score, whereas Gradia Direct has shown evenly distributed ARI scores.

Table 3. Mean and SD of Shear Bond Strength Values for Each Group According to Restorative Material and Surface Conditioning Method

	Vita Mark II	Shofu Block HC	Brilliant Crios	Gradia Direct
Control	3.7 ± 1.1$^{B, d}$	4.4 ±1.3$^{B, c}$	6.7 ± 2.1$^{B, b}$	11.5 ±1.7$^{A, b}$
HF	15.1 ± 2.4$^{A, a}$	11.8± 2.7$^{A, ab}$	13.4 ± 1.5$^{A, a}$	15.0 ±2.2$^{A, a}$
AL	10.7 ±1.3$^{B, cb}$	14.1± 2.0$^{A, ab}$	15.7± 2.0$^{A, a}$	16.9 ± 1.6$^{A, a}$
CJ	8.0 ±1.1$^{B, c}$	14.9 ± 2.6$^{A, a}$	15.4 ± 2.1$^{A, a}$	16.2 ± 1.6$^{A, a}$
BUR	13.3 ±1.7$^{A, b}$	10.9± 3.7$^{A, b}$	14.2 ±2.7$^{A, a}$	16.3 ± 1.3$^{A, a}$
MEP	14.8 ± 2.0$^{A, ba}$	12.2 ± 1.6$^{A, ab}$	12.6 ±1.6$^{A, a}$	14.2 ± 2.7$^{A, ab}$

Different uppercase letters in each row for each restorative material indicates significant differences ($P < .05$).
Different lowercase letters in each column for each surface conditioning method indicates significant differences ($P < .05$).
AL, sandblasting with aluminum oxide; BUR, bur abrasion; CJ, tribochemical silica coating with CoJet; HF, etching with hydrofluoric acid; MEP, Monobond Etch and Prime.

Scanning electron microscope micrographs of restorative materials after surface conditioning are demonstrated in Figures 1-4. The control groups of all restorative materials presented smoother surfaces compared to HF, AL, and CJ conditioning methods. The HF created microporosities in all the restorative materials, but Vita Mark II has an evident porous structure. The AL or CJ conditioning of the specimens resulted in sharp edges with a wavy pattern caused by elevation and depression areas, especially on Shofu Block HC, Gradia Direct, and Brilliant Crios. The BUR-conditioned Gradia Direct and Brilliant Crios specimens presented coarse finishing traces while the other restorative materials had more homogeneous surfaces. In addition, MEP filled in the microporosities of the restorative materials making them seem smooth and glassy compared to the controls.

DISCUSSION

The present study investigated the influence of different surface conditioning methods on the SBS of orthodontic metal braces to different restorative materials along with a universal adhesive. Based on the findings of the present study, both the restorative material and the surface conditioning method influenced the SBS significantly, and a significant interaction between 2 factors was found. Accordingly, both null hypotheses are rejected. Previous studies also revealed that the restorative material and the surface conditioning affect the SBS and even further that surface

Table 4. Frequency (%) of Failure Types in Each Experimental Group According to Modified Adhesive Remnant Index (ARI)

Material	Conditioning Method	Score 5	Score 4	Score 3	Score 2	Score 1
Vita Mark II	Control	100	0	0	0	0
	HF	0	0	10	30	60
	AL	0	0	10	40	50
	CJ	10	10	10	20	50
	BUR	0	10	20	10	60
	MEP	0	0	20	10	70
Shofu Block HC	Control	100	0	0	0	0
	HF	10	0	0	20	70
	AL	0	0	10	10	80
	CJ	0	10	10	10	70
	BUR	0	10	10	20	60
	MEP	0	0	20	10	70
Brilliant Crios	Control	90	10	0	0	0
	HF	0	10	0	10	80
	AL	0	0	0	10	90
	CJ	0	0	0	10	90
	BUR	0	0	10	20	70
	MEP	10	0	10	10	70
Gradia Direct	Control	40	20	0	20	20
	HF	0	20	10	10	60
	AL	0	0	0	10	90
	CJ	0	10	10	10	70
	BUR	0	0	0	10	90
	MEP	0	10	0	30	60

AL, sandblasting with aluminum oxide; BUR, bur abrasion; CJ, tribochemical silica coating with CoJet; HF, etching with hydrofluoric acid; MEP, Monobond Etch and Prime.
Scores: 5 = no remnant; 4 = <10% remnant; 3 = 10%-90% remnant; 2 = >90% remnant, and 1 = 100% remnant of adhesive paste remained on the restorative material.

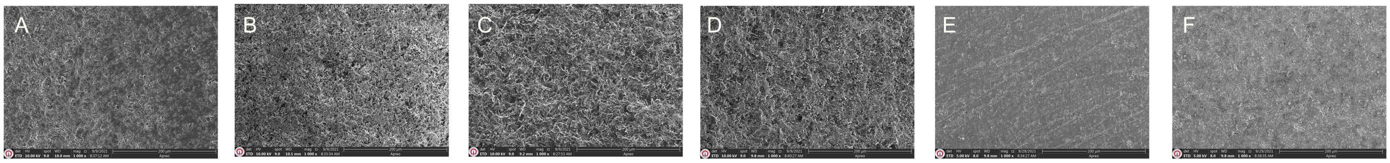

Figure 1. Scanning electron microscope micrographs of Vita Mark II exposed to different surface conditioning methods, at 1000× magnification. A, control; B, etching with hydrofluoric acid; C, sandblasting with aluminum-oxide; D, tribochemical silica coating with CoJet; E, bur abrasion; F, Monobond Etch and Prime.

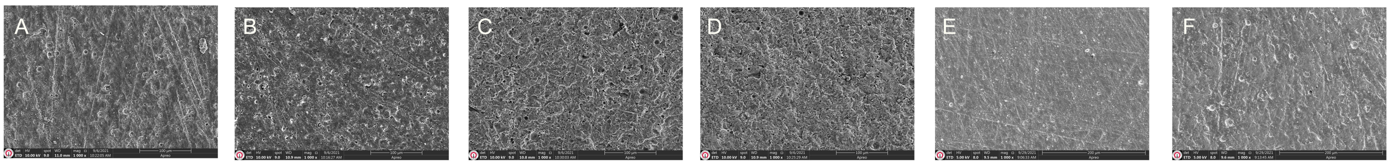

Figure 2. Scanning electron microscope micrographs of Shofu Block HC exposed to different surface conditioning methods, at 1000× magnification. A, control; B, etching with hydrofluoric acid; C, sandblasting with aluminum-oxide; D, tribochemical silica coating with CoJet; E, bur abrasion; F, Monobond Etch and Prime.

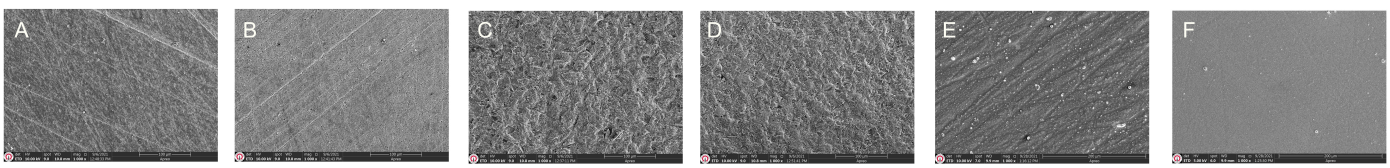

Figure 3. Scanning electron microscope micrographs of Brilliant Crios exposed to different surface conditioning methods, at 1000× magnification. A, control; B, etching with hydrofluoric acid; C, sandblasting with aluminum-oxide; D, tribochemical silica coating with CoJet; E, bur abrasion; F, Monobond Etch and Prime.

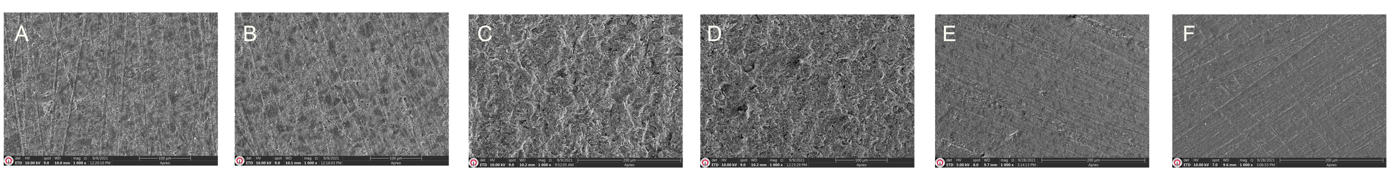

Figure 4. Scanning electron microscope micrographs of Gradia Direct exposed to different surface conditioning methods, at 1000× magnification. A, control; B, etching with hydrofluoric acid; C, sandblasting with aluminum-oxide; D, tribochemical silica coating with CoJet; E, bur abrasion; F, Monobond Etch and Prime.

conditioning increases SBS significantly ($P < .001$) which coincides with the results of our study.[28,29] An increase in SBS associated with surface conditioning could be related to higher surface roughness that enhances the penetration of bonding agents.[30]

Conventional adhesive systems require high technical sensitivity and more time, due to multiple application steps. Therefore, to overcome these disadvantages, universal adhesives which can be used in self-etch or etch-and-rinse modes in single-step are developed. In addition, they can be applied to different types of restorative materials to enhance bonding performance.[14] Previous studies reported that universal adhesives can sustain adequate bond strength between orthodontic metal braces and resin composites even without extra surface conditioning which supports the findings of this study.[31,32] In addition, ARI scores of the control group of Gradia Direct presented an even distribution proving high SBS between the adhesive resin and the restorative material.[3] Furthermore, Essayagh Tourot et al[33] concluded that SBS values between orthodontic metal braces and lithium disilicate ceramics, conditioned with universal adhesive, appear to be sufficient. However, in the present study, conditioning feldspar ceramic with a universal adhesive did not demonstrate adequate bond strength which is reported to be 6-8 MPa.[3,19] Moreover, the ARI score of this group showed that no adhesive resin remained on Vita Mark II specimens. Therefore, an additional surface conditioning method is required to increase the SBS.

For conditioning glass ceramics, it is reported that the application of HF and silane is considered the gold standard.[15,34] The HF creates surface roughness by the dissolution of the glassy phase as demonstrated in SEM images of Vita Mark II, in a previous study and the present study.[28] This results in promoted micromechanical retention and thereby increases the SBS.[29] El-Damanhoury and Gaintantzopoulou[35] also suggested that conditioning with 9.6% HF and silane or bonding agent application afterward provides the highest SBS for ceramics. In the present study, after HF, the surface was conditioned with a silane-incorporated universal adhesive and the results showed that mostly HF promoted the SBS values observed for Vita Mark II. Also, regarding resin-matrix ceramic blocks (Shofu Block HC and Brilliant Crios) and direct composite resin (Gradia Direct), HF again significantly increased the SBS values. This is probably because HF etches the glassy filler component and creates micropores through the resin matrix which increases the surface energy and wettability of bonding agents.[21] Although surface conditioning with HF along with silane or bonding agents proved to increase SBS, it may damage the ceramic surface during debonding.[14] In addition, clinicians should take safety precautions while using HF intraorally as it has a hazardous effect on soft tissues.[13]

Mechanical surface conditioning methods can be considered as an alternative since hydrofluoric acid etching has potential side effects.[35] One of these methods is sandblasting with aluminum oxide particles which results in micro-retentive porous surfaces.[36] The other one is tribochemical silica coating which can increase bond strength by abrading the restorative material and producing micromechanical retention and by chemical bonding along with silane.[37] Considering the SEM images of this study, both the AL and the CJ caused laminar porosities, with significant irregularities that possibly expanded the surface area and provided micromechanical interlocking. Regarding the SBS values, these methods increased the SBS significantly in all restorative materials that have resin components. Supportingly, according to the ARI scores, Gradia Direct specimens conditioned with AL and Brilliant Crios specimens conditioned with AL or CJ presented the highest incidence of score 1 related to high bond strength whereas Vita Mark II conditioned with AL or CJ had the lowest incidence of score 1, referring to lower bond strength. In previous studies that analyzed the SBS between metal braces and resin matrix ceramic blocks or direct resin composites, it was found that sandblasting provided the highest SBS values.[22,36] In addition, Turunç-Oğuzman and Şişmanoğlu[28] found that CJ enhanced SBS values for resin matrix ceramics significantly which is in line with the present study. This can be explained by that the silane inside the universal adhesive chemically bonds with both the silica and the methacrylate part of the resin matrix ceramics and the direct resin composite, resulting in an increase in SBS values.[38]

Another mechanical surface conditioning method is surface abrasion using a diamond bur, which is practical in the clinic as it eliminates the need for an additional instrument. It creates macro and micro-retentive surfaces by forming deep grooves and scratches.[39] In this study, the BUR method significantly increased the SBS values demonstrated by Gradia Direct and Brilliant Crios specimens; however, it was not successful for Vita Mark II and Shofu Block HC specimens regarding the SBS advancement. This might be because SEM images of Gradia Direct and Brilliant Crios specimens presented coarse polishing traces that could contribute to retention, while the SEM images of Vita Mark II and Shofu Block HC presented more homogeneous surfaces. The significant differences in SBS values found for different restorative materials are probably related to the variations in the chemical components, the type of organic matrix, the type of inorganic fillers and their ratios, and the manufacturing techniques. These are the factors that influence the materials' properties and their reaction to different surface conditioning methods and thereby affecting the SBS.[15,22] Considering this, relatively low SBS values demonstrated by Vita Mark II samples conditioned with AL, CJ, or BUR could be explained by its chemical composition which has glass ceramic, but no organic component. Still, all the mechanical conditioning methods enhanced the SBS values, and they were all clinically acceptable, above 6 MPa.[3,19] However, they have possible adverse effects on restorative materials such as chipping, heat production, and residual stresses which might reduce bond strength or general respiratory tract irritations.[17]

Monobond Etch and Prime, a self-etching ceramic primer can be used as a chemical conditioning method to eliminate the adverse effects of mechanical conditioning methods. Monobond Etch and Prime is produced to make the surface conditioning protocol easier for indirect restorative placement procedures. It simultaneously etches the restorative material with a mild acid (ammonium polyfluoride) and provides silanization (trimethoxypropyl methacrylate) in a single step.[18] Previous studies on the SBS of metal braces to dental ceramic CAD/CAM blocks, including resin nanoceramic, resin composite, hybrid ceramic, feldspar ceramic, and reinforced glass-ceramic blocks, have reported that MEP's efficiency is promising, better than the control group, but not as good as manufacturer instructions.[21,22,28] Moreover, a recent study reported that it causes lower SBS values compared to the two separate steps of etching and silanization since MEP consists of a weaker acid (pH=4.4).[40] Therefore, in the present study, the MEP-conditioned specimens were conditioned with a universal adhesive which has a lower pH (pH=2.7) value than ammonium polyflouride (pH=4.4) to evaluate if it increases SBS values.[41] Based on the findings of this study, MEP application along with universal adhesive increased the SBS values as significantly as the manufacturer instructions for all materials, except direct resin composite. Still, all restorative materials, including direct resin composite, demonstrated sufficient SBS values for metal brace bonding.

Regarding the results of this study, it can be derived that MEP along with a universal adhesive could be a better option for surface conditioning to enhance adhesion between orthodontic braces and dental CAD/CAM blocks. Because of the problems related to other surface conditioning methods, referred earlier, MEP might be a safer alternative because it is not harmful for a short contact time. In addition, since it is not influenced significantly by contamination of saliva, there is no necessity to take precautions, which makes it also practical.[42] Regarding the results of the current study and the previous studies about MEP's performance on various dental CAD/CAM blocks with different compositions[18-22,28], it can be derived that MEP along with a universal adhesive can be a suitable surface conditioning method, close to manufacturer instructions, for all tooth-colored CAD/CAM blocks that clinicians are not certain of the formulation.

There are various limitations associated with this study. Primarily, in vitro studies do not present an exact reflection of intra-oral conditions with regard to biofilm existence, masticatory forces, and thermal changes that can influence SBS.[3,21] However, to simulate aging, samples were exposed to thermal cycling before surface conditioning and after bonding of the braces for 5000 cycles as administered in previous studies too.[23,24] Furthermore, to simulate the diamond bur, sandpaper was used for surface conditioning as referred to in previous studies to achieve standardization[25,26], but this might have caused a smoother surface that can be observed on SEM images and decreased the SBS results. Further laboratory and clinical studies should be accomplished, eliminating these restrictions, to confirm the findings of this study. In addition, future studies can assess different restorative materials to make sure MEP is an appropriate surface conditioning method for all dental ceramic types. Moreover, surface roughness and surface wettability of the restorative materials can be evaluated after surface conditioning methods.

In conclusion, surface conditioning methods significantly enhance the SBS, but the amount of increase also depends on the restorative material. Application of a universal adhesive alone (control group) maintained adequate bond strength for light-cured micro-hybrid composite (Gradia Direct) and reinforced composite block (Brilliant Crios), but additional surface conditioning should be considered for feldspathic ceramic (Vita Mark II) and hybrid ceramic (Shofu Block HC) blocks which had SBS values below 6 MPa. As a safer and more practical method of surface conditioning, MEP along with a universal adhesive can be used on all restorative materials tested, with adequate adhesion of orthodontic metal braces.

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REFERENCES

1. Mcmorrow SM, Millett DT. Adult orthodontics in the Republic of Ireland : specialist orthodontists' opinions. *J Orthod*. 2017;44(4):277-286. [CrossRef]
2. Sandhya A, Harish B, Senthil Murugan P. Proportion of orthodontic patients seeking adult orthodontic treatment. *Int J Dent Oral Sci*. 2021;8(7):3074-3078.
3. Yüzbaşıoğlu E, Sayar-Torun G, Özcan M. Adhesion of orthodontic brackets to indirect laboratory-processed resin composite as a function of surface conditioning methods and artificial aging. *J Adhes Sci Technol*. 2016;30(23):2565-2572. [CrossRef]
4. Suganna M, Kausher H, Tarek Ahmed S, et al. Contemporary evidence of CAD-CAM in dentistry: A systematic review. *Cureus*. 2022;14(11):e31687. [CrossRef]
5. Giordano R. Materials for chairside CAD/CAM-produced restorations. *J Am Dent Assoc*. 2006;137(9 suppl):14S-21S. [CrossRef]
6. Ruse ND, Sadoun MJ. Resin-composite Blocks for Dental CAD/CAM applications. *J Dent Res*. 2014;93(12):1232-1234. [CrossRef]
7. Awada A, Nathanson D. Mechanical properties of resin-ceramic CAD/CAM restorative materials. *J Prosthet Dent*. 2015;114(4):587-593. [CrossRef]
8. Coldea A, Swain MV, Thiel N. Mechanical properties of polymer-infiltrated-ceramic-network materials. *Dent Mater*. 2013;29(4):419-426. [CrossRef]
9. Stasinopoulos D, Papageorgiou SN, Kirsch F, Daratsianos N, Jäger A, Bourauel C. Failure patterns of different bracket systems and their influence on treatment duration : A retrospective cohort study. *Angle Orthod*. 2018;88(3):338-347. [CrossRef]
10. Bayel Akgül M, Uslu F. Evaluation of the effects of ultrasonic device and sandblasting techniques on shear bond strength before rebonded brackets with different base designs. *Curr Res Dent Sci*. 2022;32(4):253-260. [CrossRef]
11. Alzainal AH, Majud AS, Al-Ani AM, Mageet AO. Orthodontic bonding: review of the literature. *Int J Dent*. 2020;2020:8874909. [CrossRef]
12. Tayebi A, Fallahzadeh F, Morsaghian M. Shear bond strength of orthodontic metal brackets to aged composite using three primers. *J Clin Exp Dent*. 2017;9(6):e749-e755. [CrossRef]
13. Francisco I, Travassos R, Nunes C, et al. What is the most effective technique for bonding brackets on ceramic—A systematic review and meta-analysis. *Bioengineering (Basel)*. 2022;9(1):14. [CrossRef]
14. Golshah A, Mohamadi N, Rahimi F, Pouyanfar H, Tabaii ES, Imani MM. Shear bond strength of metal brackets to porcelain using a universal adhesive. *Med Arch*. 2018;72(6):425-429. [CrossRef]
15. Peumans M, Valjakova EB, De Munck J, Mishevska CB, Van Meerbeek B. Bonding effectiveness of luting composites to different CAD/CAM materials. *J Adhes Dent*. 2016;18(4):289-302. [CrossRef]
16. 3M™ CoJet Sand; 68411; 3M Company: 3M Center, St. Paul, MN, USA. Available at: https://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSuUn_zu8l00x482v58mZMv70k17zHvu9lxtD7SSSSSS. Access04/23/20. Accessed April 23, 2020.
17. Albakry M, Guazzato M, Swain MV. Effect of sandblasting , grinding , polishing and glazing on the flexural strength of two pressable all-ceramic dental materials. *J Dent*. 2004;32(2):91-99. [CrossRef]
18. Colombo LDA, Murillo-Gómez F, De Goes MF. Bond strength of CAD/CAM restorative materials treated with different surface etching protocols. *J Adhes Dent*. 2019;21(4):307-317. [CrossRef]
19. Recen D, Yıldırım B, Othman E, Çömlekoğlu E, Aras I. Bond strength of metal brackets to feldspathic ceramic treated with different surface conditioning methods: an in vitro study. *Eur Oral Res*. 2021;55(1):1-7. [CrossRef]
20. Franz A, Raabe M, Lilaj B, et al. Effect of two different primers on the shear bond strength of metallic brackets to zirconia ceramic. *BMC Oral Health*. 2019;19(1):51. [CrossRef]
21. González-Serrano C, Phark JH, Fuentes MV, et al. Effect of a single-component ceramic conditioner on shear bond strength of precoated brackets to different CAD/CAM materials. *Clin Oral Investig*. 2021;25(4):1953-1965. [CrossRef]
22. de Almeida RM, Hass V, Sasaki DY, Berger SB, Fernandes TM, Tonetto MR. The impact of different surface treatments on the shear bond strength of orthodontic metal brackets applied to different CAD/CAM composites. *J Clin Exp Dent*. 2021;13(6):e608-e613. [CrossRef]
23. Alavi S, Shirani F, Zarei Z, Raji SAH. Effect of different surface treatment with panaviaV5 on shear bond strength of metal brackets to silver amalgam. *Dent Res J (Isfahan)*. 2021;18(9):9
24. Asiry MA, AlShahrani I, Alaqeel SM, Durgesh BH, Ramakrishnaiah R. Effect of two-step and one-step surface conditioning of glass ceramic on adhesion strength of orthodontic bracket and effect of thermo-cycling on adhesion strength. *J Mech Behav Biomed Mater*. 2018;84:22-27. [CrossRef]
25. Kim JW, Covel NS, Guess PC, Rekow ED, Zhang Y. Concerns of hydrothermal degradation in CAD/CAM Zirconia. *J Dent Res*. 2010;89(1):91-95. [CrossRef]
26. Wiegand A, Stucki L, Hoffmann R, Attin T, Stawarczyk B. Repairability of CAD/CAM high-density PMMA- and composite-based polymers. *Clin Oral Investig*. 2015;19(8):2007-2013. [CrossRef]
27. Bishara SE, VonWald L, Laffoon JF, Warren JJ. Effect of a self-etch primer/adhesive on the shear bond strength of orthodontic brackets. *Am J Orthod Dentofacial Orthop*. 2001;119(6):621-624. [CrossRef]

28. Turunç-Oğuzman R, Şişmanoğlu S. Effect of surface treatments on shear bond strength between CAD/CAM bioceramic and resin blocks and orthodontic metal brackets bonded to each other. *J Aust Ceram Soc*. 2023;59(1):187-196. [CrossRef]
29. Şişmanoğlu S, Turunç-Oğuzman R. Microshear bond strength of contemporary self-adhesive resin cements to CAD/CAM restorative materials: effect of surface treatment and aging. *J Adhes Sci Technol*. 2020;34(22):2484-2498. [CrossRef]
30. Matinlinna JP, Lung CYK, Tsoi JKH. Silane adhesion mechanism in dental applications and surface treatments: a review. *Dent Mater*. 2018;34(1):13-28. [CrossRef]
31. Tahmasbi S, Badiee M, Modarresi M. Shear bond strength of orthodontic brackets to composite restorations using universal adhesive. *J Dent (Shiraz)*. 2019;20(2):75-82. [CrossRef]
32. Pouyanfar H, Golshah A, Shekarbeigi M. Shear bond strength of metal and ceramic brackets to composite using single bond and universal adhesives. *Open Access Maced J Med Sci*. 2020;8(D):1-6. [CrossRef]
33. Essayagh Tourot JE, Dantagnan CA, Francois P, Dursun E, Attal JP. In vitro study evaluating the shear bond strength of metal brackets to lithium disilicate ceramic support using a universal adhesive. *Orthod Fr*. 2022;93(2):101-109. [CrossRef]
34. Gilbert S, Keul C, Roos M, Edelhoff D, Stawarczyk B. Bonding between CAD/CAM resin and resin composite cements dependent on bonding agents: three different in vitro test methods. *Clin Oral Investig*. 2016;20(2):227-236. [CrossRef]
35. El-Damanhoury HM, Gaintantzopoulou MD. Self-etching ceramic primer versus hydrofluoric acid etching: etching efficacy and bonding performance. *J Prosthodont Res*. 2018;62(1):75-83. [CrossRef]
36. Zarif Najafi H, Mousavi M, Nouri N, Torkan S. Evaluation of the effect of different surface conditioning methods on shear bond strength of metal brackets bonded to aged composite restorations. *Int Orthod*. 2019;17(1):80-88. [CrossRef]
37. Nergiz I, Schmage P, Herrmann W, Özcan M. Effect of alloy type and surface conditioning on roughness and bond strength of metal brackets. *Am J Orthod Dentofacial Orthop*. 2004;125(1):42-50. [CrossRef]
38. Özcan M, Vallittu PK. Effect of surface conditioning methods on the bond strength of luting cement to ceramics. *Dent Mater*. 2003;19(8):725-731. [CrossRef]
39. Bayram M, Yeşilyurt C, Kuşgöz A, Ülker M, Nur M. Shear bond strength of orthodontic brackets to aged resin composite surfaces: effect of surface conditioning. *Eur J Orthod*. 2011;33(2):174-179. [CrossRef]
40. Özarslan MM, Üstün Ö, Buyukkaplan US, Barutcigil Ç, Türker N, Barutcigil K. Assessment the bond strength of ceramic brackets to CAD/CAM nanoceramic composite and interpenetrating network composite after different surface treatments. *BioMed Res Int*. 2018;2018:1871598. [CrossRef]
41. Shintani H, Isozaki A, Kuwahara Y, Ikuta S, Kani M, Kani T. The effect of ammonium fluoride solution at various concentrations on enamel. *Gifu Shika Gakkai Zasshi*. 1990;17(1):170-176
42. Lyann SK, Takagaki T, Nikaido T, et al. Efficacy of various surface treatments on the bonding performance of saliva-contaminated lithium-disilicate ceramics. *J Adhes Dent*. 2019;21(1):51-58. [CrossRef]