Original Article

Biomechanical evaluation between orthodontic attachment and three different materials after various surface treatments: *A three-dimensional optical profilometry analysis*

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ABSTRACT

Objectives: To determine the best bonding method of orthodontic attachment among monolithic zirconia, feldspathic porcelain, hybrid porcelain, and the impact of surface-conditioning methods using a three-dimensional optical profilometer after debonding.

Materials and Methods: 56 feldspathic porcelain, 56 monolithic zirconia, and 56 hybrid porcelain samples were divided into four surface treatment subgroups: (1) hydrofluoric (HF) acid etch + silane, (2) Al_2O_3 sandblasting + silane, (3) silicoating (SiO_2), and (4) diamond bur + silane. The specimens were tested to evaluate shear bond strength (SBS). Residual composite was removed after debonding. Three-dimensional white-light interferometry was used to obtain quantitative measurements on surface roughness.

Results: The highest SBS value was found for the HF acid–etched feldspathic porcelain group. The average surface roughness values were significantly higher in all material groups in which diamond bur was applied, while roughening with Cojet provided average surface roughness values closer to the original material surface.

Conclusions: Variations in structures of the materials and roughening techniques affected the SBS and surface roughness findings. (*Angle Orthod.* 2019;89:742–750.)

KEY WORDS: Three-dimensional optical profilometry; Surface roughness; Shear bond strength

INTRODUCTION

The procedure of attachment bonding may be more complicated in adult orthodontic patients because of the high incidence of dental restorations in this group. These restorations may be feldspathic porcelain, hybrid porcelain, or zirconium-based ceramic restorations, which have been increasingly preferred for esthetic and durability benefits. To date, several studies have addressed different surface-conditioning methods for orthodontic bonding to porcelain.[1–4] A recently introduced air abrasion technique, based on tribochemical silica coating, provides not only mechanical retention by sandblasting but also chemicophysical bonding between the composite resin and the restoration through the use of a silane coupling agent. Restoration surfaces are blasted with 30 μm CoJet Sand (ESPE, Seefeld, Germany) with an intraoral sandblaster. However, there are insufficient data on the success of the bonding of orthodontic attachments to monolithic zirconia and hybrid ceramic materials, as they are relatively newer materials in dental practice.[5–8]

The aims of this study were therefore to evaluate the shear bond strength (SBS) of orthodontic attachments bonded to feldspathic porcelain, monolithic zirconia, and hybrid porcelain after various surface-conditioning methods and to evaluate the surface properties after debonding and polishing.

The null hypotheses tested in this study were the following:

1. The SBS of orthodontic attachments is not affected by the type of material.

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2. The SBS of orthodontic attachments is not affected by the surface-conditioning method.
3. Surface roughness after debonding is not affected by the type of the material.
4. Surface roughness after debonding is not affected by the surface-conditioning method.

MATERIALS AND METHODS

This project was approved by the Research Ethics Committee of Baskent University School of Dentistry (protocol DK-2015/05). A power analysis was conducted to determine the sample size needed using a significance level of .05 and a power of 0.80. The resulting sample size was 50 specimens per group.

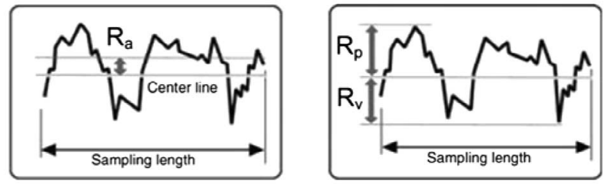
Specimen Preparation

The materials used in this study were feldspathic ceramic (Vita Block), hybrid ceramic (Vita Enamic), and monolithic zirconia (Vita YZTP), all of which were supplied as Vita brand (Zahnfabrik, Bad Säckingen, Germany). Blocks were cut to a size of 6 × 7 × 2 mm with a Micracut 201 device (Metkon, Bursa, Turkey) so that each group had 56 specimens. Ceramic blocks were obtained from the manufacturer preglazed, whereas zirconia samples were subjected to sintering for 30 minutes at 1450°C. The monolithic zirconia specimens were cut to be approximately 25% greater than the size of the sintered specimens to compensate for sintering shrinkage. All specimens were embedded in cold-curing acrylic blocks, ensuring that the glazed and polished surfaces were exposed.

Surface-Conditioning Methods

The pretreatment methods used on the restoration surfaces were as follows:

- Group 1 (hydrofluoric [HF] acid + silane): 9.6% HF acid (Pulpdent, Watertown, Mass) was applied to the material surface for 2 minutes. After removing excess acid, the samples were washed with pressurized water for 15 seconds and dried with air for 20 seconds. Silane (ESPE-Sil, 3M ESPE, Seefeld, Germany) was applied as a single layer with a brush and left to dry.[9–15]
- Group 2 (sandblasting with Al_2O_3 + silane): The specimen surfaces were subjected to sandblasting with 50 μm Al_2O_3 powder (Pureblast White No. 100-3954, Henry Schein, Melville, NY) with an intraoral air-abrasion device (Microetcher II, Danville Materials, Oakland, Calif), applied perpendicular to the sample surfaces from a distance of 10 mm for 10 seconds in circling motions at 2.5 bar pressure. Silane was applied after the removal of debris from the surfaces.[9–13]
- Group 3 (silica coating with Cojet + silane): The surfaces were subjected to sandblasting with 30 μm SiO_2 sand (Cojet-Sand, 3M ESPE) with an intraoral sandblasting device (Microetcher II, Danville Materials) under 2.5 bar pressure, at a 10-mm distance for 10 seconds.[16]



$$R_a = \frac{1}{L}\int_0^L |z(x)|dx \qquad R_t = R_p + R_v$$

$$R_{ku} = \frac{1}{n(R_q)^4}\sum_{i=1}^{i=n}(Y_i)^4 \qquad R_{sk} = \frac{1}{n(R_q)^3}\sum_{i=1}^{i=n}(Y_i)^3$$

Figure 1. Equations used by image analysis software for calculation of the selected surface roughness parameters.

Table 1. Shear Bond Strength Comparison of Tooth Group, Materials, and Surface-Conditioning Methods*

	Feldspathic Porcelain	Monolithic Zirconia	Hybrid Ceramic	*P* Value**
HF acid	8.84 (6.38–10.07)[A,B,a,b,c,x]	5.38 (4.77–5.67)[A,a,b,c,x]	4.07 (3.32–5.94)[B,a,b,c,x]	<.001
Al_2O_3	1.53 (1.23–1.83)[A,a,d]	0.73 (0.59–0.92)[A,C,a,d,e,x]	1.74 (1.25–2.07)[C,a]	<.001
Cojet	1.89 (1.72–2.20)[b]	2.24 (1.80–2.57)[b,e]	1.85 (1.41–2.45)[b]	.197
Diamond bur	2.24 (1.72–2.98)[A,B,c,d]	1.65 (1.47–1.80)[A,C,c,d]	1.36 (1.05–1.75)[B,C,c,x]	<.001
P value***	<.001	<.001	<.001	

* Data are shown as median (25th–75th) percentiles. Superscript letters indicate the following: A, porcelain vs zirconia ($P < .001$); B, porcelain vs Enamic ($P < .001$); C, zirconia vs Enamic ($P < .0125$); a, HF acid vs Al_2O_3 ($P < .001$); b, HF acid vs Cojet ($P < .01$); c, HF acid vs diamond bur ($P < .001$); d, Al_2O_3 vs diamond bur ($P < .01$); e, Al_2O_3 vs Cojet ($P < .001$); x, according to the Bonferroni correction, the differences between tooth groups were statistically significant ($P < .0042$).

** The comparisons among materials within each type of chiseling, Kruskal-Wallis test, according to the Bonferroni correction $P < .0125$, was considered as statistically significant.

*** The comparisons among chiseling types within each material, Kruskal-Wallis test, according to the Bonferroni correction $P < .017$, was considered as statistically significant.

Table 2. Surface Roughness Comparison of Materials and Surface-Conditioning Methods*

	Feldspathic Porcelain	Monolithic Zirconia	Hybrid Ceramic	*P* Value**
PV				
HF acid	36.2 (29.6 to 47.2)^{A,a}	85.1 (75.1 to 106.0)^{A,B,d,e}	28.1 (20.5 to 33.5)^{B,d,e}	<.001
Al_2O_3	36.8 (25.4 to 52.9)^{C,b}	24.6 (21.4 to 36.2)^{B,b,d}	88.1 (81.6 to 109.7)^{B,C,b,d,f}	<.001
Cojet	81.3 (72.6 to 93.1)^{C,a,b,c}	71.0 (63.8 to 88.9)^{B,b,c}	34.6 (22.9 to 38.7)^{B,C,b}	<.001
Diamond bur	44.5 (36.3 to 59.1)^{c}	30.5 (12.1 to 52.6)^{c,e}	40.3 (32.0 to 49.9)^{e,f}	.197
P value***	<.001	<.001	<.001	
Rms				
HF acid	1.05 (0.49 to 1.53)	1.25 (0.74 to 2.45)^{d}	0.58 (0.40 to 0.70)^{d,e}	.017
Al_2O_3	1.17 (0.88 to 1.39)^{A,C}	0.42 (0.35 to 0.51)^{A,B,b,d,f}	1.98 (1.32 to 3.19)^{B,C,b,d}	<.001
Cojet	0.94 (0.68 to 1.33)	0.86 (0.42 to 0.98)^{b}	0.63 (0.52 to 0.93)^{b,c}	.162
Diamond bur	1.41 (0.77 to 1.72)	1.09 (0.84 to 1.63)^{f}	1.05 (0.83 to 1.99)^{c,e}	.867
P value***	.528	<.001	<.001	
Ra				
HF acid	0.39 (0.28 to 0.56)^{d,e}	0.51 (0.26 to 1.19)^{a,e}	0.39 (0.26 to 0.46)^{d,e}	.682
Al_2O_3	0.89 (0.68 to 1.10)^{A,b,d}	0.31 (0.27 to 0.36)^{A,B,f}	0.75 (0.43 to 1.30)^{B,d}	<.001
Cojet	0.28 (0.21 to 0.57)^{C,b,c}	0.28 (0.20 to 0.35)^{B,a,c}	0.47 (0.40 to 0.74)^{B,C,c}	.004
Diamond bur	0.92 (0.83 to 1.10)^{c,e}	0.81 (0.65 to 1.27)^{c,e,f}	0.81 (0.57 to 1.47)^{c,e}	.613
P value***	<.001	<.001	<.001	
Rsk				
HF acid	3.8 (2.4 to 4.8)^{a,d,e}	6.5 (0.9 to 24.2)^{e}	3.1 (1.5 to 5.4)^{a,e}	.322
Al_2O_3	−0.4 (−0.8 to 0.1)^{A,C,b,d}	0.5 (−0.1 to 2.6)^{A,B,b}	7.7 (4.5 to 13.5)^{B,C,b,f}	<.001
Cojet	19.2 (9.6 to 25.5)^{C,a,b,c}	21.5 (13.3 to 28.2)^{B,b,c}	0.7 (0.2 to 1.5)^{B,C,a,b}	<.001
Diamond bur	−1.0 (−1.4 to 0.03)^{C,c,e}	−0.4 (−1.0 to 0.4)^{B,c,e}	0.6 (0.1 to 1.1)^{B,C,e,f}	.002
P value***	<.001	<.001	<.001	
Rku				
HF acid	101.3 (84.1 to 109.3)^{d,e}	449.5 (90.6 to 1545.1)^{d,e}	82.4 (44.9 to 216.7)^{a,e}	.037
Al_2O_3	5.4 (4.2 to 13.3)^{A,C,b,d}	36.9 (25.9 to 182.0)^{A,B,b,d}	155.9 (83.8 to 315.9)^{B,C,b,f}	<.001
Cojet	1054.8 (274.7 to 1476)^{C,b,c}	896.2 (540.4 to 2030)^{B,b,c}	18.3 (5.4 to 48.0)^{B,C,a,b}	<.001
Diamond bur	35.0 (28.3 to 54.0)^{A,C,c,e}	4.2 (3.3 to 13.1)^{A,c,e}	13.5 (7.0 to 27.9)^{C,e,f}	<.001
P value***	<.001	<.001	<.001	

* Data are shown as median (25th–75th) percentiles. Superscript letters indicate the following: A, porcelain vs zirconia ($P < .01$); B, zirconia vs Enamic ($P < .01$); C, porcelain vs Enamic ($P < .01$); a, HF acid vs Cojet ($P < .017$); b, Al_2O_3 vs Cojet ($P < .01$); c, Cojet vs diamond bur ($P < .01$); d, HF acid vs Al_2O_3 ($P < .001$); e, HF acid vs diamond bur ($P < .017$); f, Al_2O_3 vs diamond bur ($P < .01$).

** The comparisons among materials within each type of chiseling, Kruskal-Wallis test, according to the Bonferroni correction $P < .0125$, was considered as statistically significant.

*** The comparisons among chiseling types within each material, Kruskal-Wallis test, according to the Bonferroni correction $P < .017$, was considered as statistically significant.

- Group 4 (roughening with diamond bur + silane): The surfaces were roughened with ultrafine cylindrical diamond burs at 40,000 rpm for 10 seconds, and silane was applied.[17]

Bonding Procedure

A total of 168 metal buttons (3M Unitek, Monrovia, Calif; flat-based lingual button, model 480-100) were bonded to each conditioned material surface using a light-curing orthodontic bonding system (Transbond XT, 3M Unitek). Excess cement was removed from the button margin with a probe and light cured from the mesial and distal sides using a light-emitting diode light source (Elipar S10, 3M/Unitek) for 15 seconds.

Thermal Cycling Procedure

All specimens were subjected to thermal cycling of 1000 cycles with a 15-second waiting period and 10-second transfer period between 5 and 55°C (±5°C) in a thermal cycling device (Nuve Sanayi Malzemeleri, Ankara, Turkey).

SBS Test

The bonding resistance of buttons was assessed with a universal testing machine (LRX, Lloyd Instruments, Fareham, UK) at a cross-speed of 1 mm/min. The loading end was fixed to ensure that the shear force was parallel to the material-button interface of the specimen. The maximum force required to shear the button was recorded in Newtons and converted into megapascal ($MPa = N/mm^2 \times 0.980665$).

Surface Roughness Evaluation

Following the SBS test, any visible residual resin on specimens for each of the monolithic zirconia, hybrid ceramic, and feldspathic ceramic groups was removed using a Stainbuster bur (Abrasive Technology Ltd, London, UK) cooled with water. After removal, the

Table 3. Surface Roughness Comparison of Unprocessed Materials and Material Subgroups[a]

	Feldspathic Porcelain	Monolithic Zirconia	Hybrid Ceramic
PV			
HF acid	36.2 (29.6 to 47.2)[b]	85.1 (75.1 to 106.0)[c]	28.1 (20.5 to 33.5)
Al_2O_3	36.8 (25.4 to 52.9)[b]	24.6 (21.4 to 36.2)[c]	88.1 (81.6 to 109.7)[d]
Cojet	81.3 (72.6 to 93.1)[b]	71.0 (63.8 to 88.9)[c]	34.6 (22.9 to 38.7)
Diamond bur	44.5 (36.3 to 59.1)[b]	30.5 (12.1 to 52.6)[c]	40.3 (32.0 to 49.9)
Rms			
İG	0.22 (0.18 to 0.35)	0.24 (0.22 to 0.50)	0.45 (0.28 to 0.47)
HF acid	1.05 (0.49 to 1.53)[b]	1.25 (0.74 to 2.45)[c]	0.58 (0.40 to 0.70)
Al_2O_3	1.17 (0.88 to 1.39)[b]	0.42 (0.35 to 0.51)	1.98 (1.32 to 3.19)[d]
Cojet	0.94 (0.68 to 1.33)[b]	0.86 (0.42 to 0.98)	0.63 (0.52 to 0.93)[d]
Diamond bur	1.41 (0.77 to 1.72)[b]	1.09 (0.84 to 1.63)[c]	1.05 (0.83 to 1.99)[d]
Ra			
İG	0.19 (0.12 to 0.25)	0.22 (0.15 to 0.37)	0.36 (0.25 to 0.49)
HF acid	0.39 (0.28 to 0.56)[b]	0.51 (0.26 to 1.19)	0.39 (0.26 to 0.46)
Al_2O_3	0.89 (0.68 to 1.10)[b]	0.31 (0.27 to 0.36)	0.75 (0.43 to 1.30)
Cojet	0.28 (0.21 to 0.57)	0.28 (0.20 to 0.35)	0.47 (0.40 to 0.74)
Diamond bur	0.92 (0.83 to 1.10)[b]	0.81 (0.65 to 1.27)[c]	0.81 (0.57 to 1.47)[d]
Rsk			
İG	0.06 (–0.15 to 0.22)	0.05 (−1.2 to 0.6)	0.3 (−0.3 to 0.7)
HF acid	3.8 (2.4 to 4.8)[b]	6.5 (0.9 to 24.2)[c]	3.1 (1.5 to 5.4)[d]
Al_2O_3	−0.4 (−0.8 to 0.1)	0.5 (−0.1 to 2.6)	7.7 (4.5 to 13.5)[d]
Cojet	19.2 (9.6 to 25.5)[b]	21.5 (13.3 to 28.2)[c]	0.7 (0.2 to 1.5)
Diamond bur	−1.0 (−1.4 to 0.03)[b]	−0.4 (−1.0 to 0.4)	0.6 (0.1 to 1.1)
Rku			
İG	2.1 (1.2 to 2.2)	1.6 (0.7 to 2.2)	25.4 (20.6 to 36.1)
HF acid	101.3 (84.1 to 109.3)[b]	449.5 (90.6 to 1545.1)[c]	82.4 (44.9 to 216.7)[d]
Al_2O_3	5.4 (4.2 to 13.3)[b]	36.9 (25.9 to 182.0)[c]	155.9 (83.8 to 315.9)[d]
Cojet	1054.8 (274.7 to 1476)[b]	896.2 (540.4 to 2029.7)[c]	18.3 (5.4 to 48.0)
Diamond bur	35.0 (28.3 to 54.0)[b]	4.2 (3.3 to 13.1)[c]	13.5 (7.0 to 27.9)

[a] Data are shown as median (25th–75th) percentiles.
[b] According to the Bonferroni correction, the differences between the unprocessed porcelain group and processed porcelain group were found to be statistically significant ($P < .0038$).
[c] According to the Bonferroni correction, the differences between the unprocessed zirconia group and the processed zirconia group were found to be statistically significant ($P < .0038$).
[d] According to the Bonferroni correction, the differences between the unprocessed Enamic group and processed Enamic group were found to be statistically significant ($P < .0038$).

surfaces of the restorative materials were consecutively polished by three different grainy porcelain polishing kits (Eve Diapol Universal Diamond Polishing Kit, EVE-RA305, Keltern, Germany). The purpose of this procedure was to examine how the material surface restored its originality when cleaned and polished after debonding. Thirteen specimens from each group were tested in an optical profilometer for surface evaluation.

Surface roughness was assessed using a three-dimensional (3D) optical profilometer (New View 7200, Zygo Corporation, Chicago, Ill). This device is a screening white-light interferometer composing a 3D surface image using the frequency domain analysis) method.

This 3D optical profilometer system featured rapid and contact-free screening. While the depth analysis was at a subnanometer level (0.1 nm), the lateral analysis was high (>0.5 μm). Measurements were taken from three points on the long axis of the examined surface (long axis of the material and 500 lm bilateral). Average roughness (Ra), total roughness (PV), kurtosis (Rku), and skewness (Rsk) values were measured with a separate formula for each unit (Figure 1):

1. Ra (average roughness): The arithmetical mean deviation of all points from a plane fit to the test part surface.
2. PV (total roughness): The absolute value between the highest and lowest peaks on the sample.
3. Rku (kurtosis): The measure of the randomness of heights and of the "sharpness" of a surface.
4. Rsk (skewness): The measure of symmetry of the profile about the mean line. Negative skew indicated a predominance of valleys, whereas positive skew indicated a "peaky" surface.

Statistical Analysis

Data were analyzed using IBM SPSS 17.0 (IBM Corporation, Armonk, NY) software. The normality of distribution was assessed with the Kolmogorov-Smir-

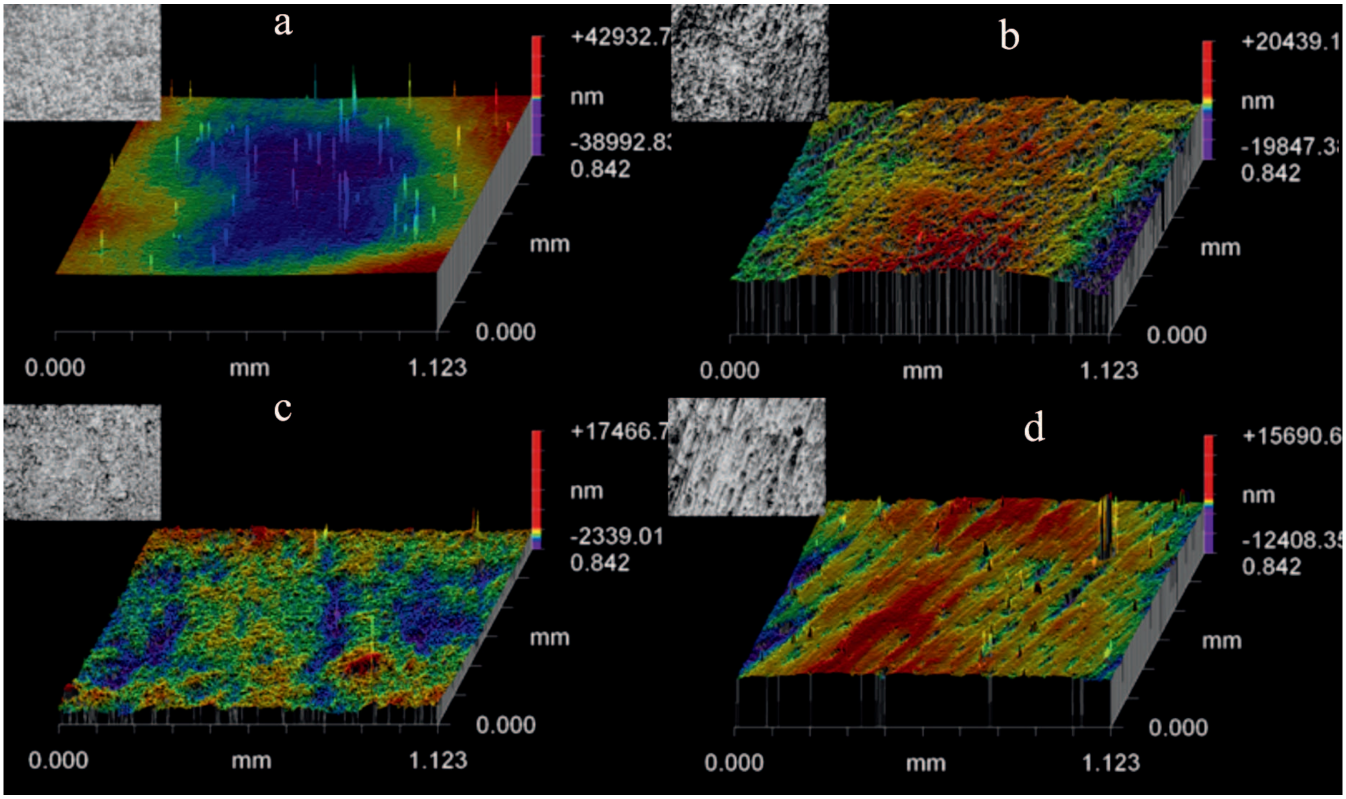


Figure 2. Three-dimensional oblique surface plots (interferograms) of a representative specimen from the Enamic group conditioned with (a) Al_2O_3, (b) diamond bur, (c) Cojet, (d) HF acid. In each figure, the solid plot (left upper corner) depicts the surface texture when viewed perpendicularly.

nov test, and homogeneity of variance was assessed with the Levene test.

The significance of the difference among the groups in terms of nonnormally distributed continuous numeric variables was assessed using the Mann-Whitney *U* and Kruskal-Wallis tests when the number of independent groups were two and more than two, respectively. When the Kruskal-Wallis test showed a significant result, Conover's multiple comparison test was used. Correlation analysis between continuous variables was applied using Spearman's correlation. Unless otherwise stated, an overall 5% type I error level was used to infer statistical significance. Bonferroni correction was performed to adjust for multiple comparisons in terms of testing of significance of type I error.

RESULTS

Shear Bond Strength

The SBS values of the materials and surface-conditioning methods are presented in Table 1. Of the materials conditioned with HF acid, the feldspathic porcelain group had the significantly highest bonding resistance (8.84). The surface-conditioning method did affect the SBS on different surfaces.

Surface Roughness

The Ra, PV, Rsk, and Rku values of the surface-conditioning subgroups are presented in Table 2 as mean (min-max) values. Within the porcelain group, the HF acid and Cojet surface-conditioning methods resulted in significantly lower average roughness (Ra) values (0.39, 0.28) compared with roughening with Al_2O_3 and diamond bur (0.89, 0.92). Likewise, the Ra values were significantly higher with Al_2O_3 and diamond bur applications (0.75, 0.81) compared with HF acid and Cojet (0.39, 0.47) on the hybrid ceramic surface. On the other hand, the diamond bur caused significantly higher Ra values when compared with the other surface-conditioning methods on the monolithic zirconia surface ($0.81 > 0.51 > 0.31 > 0.28$).

Comparisons between raw materials and processed materials are presented in Table 3. The 3D oblique surface plots (interferograms) and vertical surface plots of each test group are presented in Figures 2–5.

DISCUSSION

Orthodontists are often obliged to bond orthodontic attachments to various dental restorations. Feldspathic is a silica-based porcelain, while zirconia is non–silica-based ceramic. Hybrid ceramic is another recently

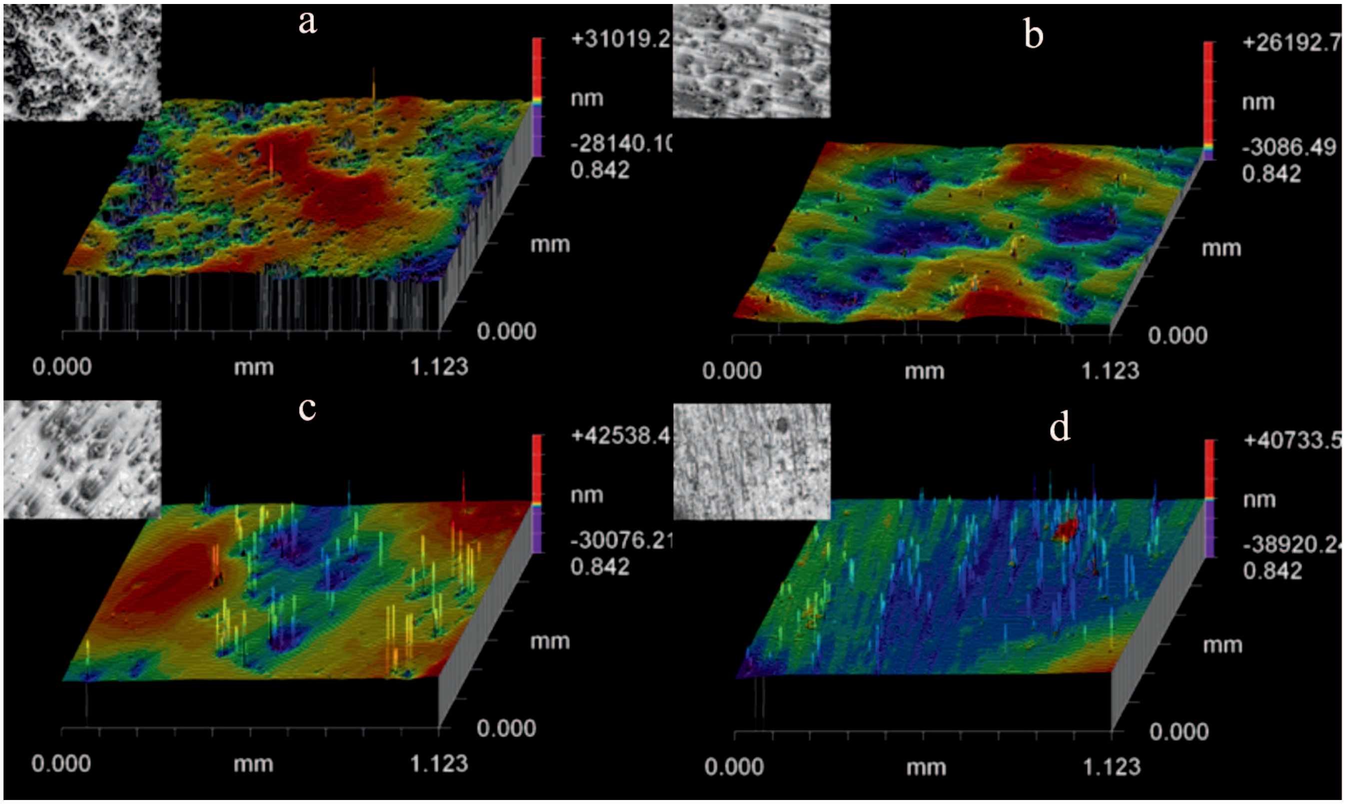


Figure 3. Three-dimensional oblique surface plots (interferograms) of a representative specimen from the feldspathic porcelain group conditioned with (a) Al_2O_3, (b) diamond bur, (c) Cojet, (d) HF acid. In each figure, the solid plot (left upper corner) depicts the surface texture when viewed perpendicularly.

developed material that combines ceramic and composite. This study aimed to assess the bonding resistance of orthodontic attachments to porcelain, hybrid ceramic, and monolithic zirconia surfaces by different surface-roughening techniques and to determine the most appropriate method. The HF acid + porcelain combination yielded the highest SBS, while Al_2O_3 sandblasting + zirconia had the lowest. Roughening the surface with HF acid modifies the material surface by partial dissolution of the glassy matrix, which contains silica and results in 5–7 μm of micro porosity and a strong micromechanical connection.[14,15] Silane is capable of forming a siloxane network with the silica in the ceramic surface, which leads to wetting and penetration of resin into those micro porosities. This could explain why the HF acid + silane and porcelain combination yielded a better SBS value. This chemical interaction is not applicable to zirconia, which lacks a silica phase.[18–22] In previous studies, applying a diamond bur to a zirconia surface did not affect the SBS.[18,19] However, sandblasting with either Al_2O_3 or Cojet is known to increase the surface area, creating microcracks and mechanical retention. Some studies have claimed that mechanical abrasion techniques cause a phase change on a zirconia surface.[23] Other studies have reported that chemical agents are more effective than mechanical conditioning in terms of bonding resistance to a zirconia surface. In contrast to the literature, the results of this study showed that the highest SBS value was found for HF acid roughening on monolithic zirconia.[24] In addition, the results of Cojet were found to be better than Al_2O_3 sandblasting, which might be due to silica-coated particles. Silica particles also have a chemical effect besides roughening the surface. The relatively lower SBS values of Al_2O_3 sandblasting might have been affected by the duration of sandblasting, the particle size of the sand, and differences in application techniques.

Regarding the biocompatibility of the surface-conditioning methods tested, HF acid acts as a metabolic toxin. When HF acid contacts the skin or mucosa, deep tissue necrosis occurs within 24 to 48 hours. Sandblasting with Al_2O_3 or Cojet can be considered as safe when compared with HF acid. This factor should also be taken into consideration when deciding on the surface-conditioning technique.

Another aim of the study was the evaluation of the surface characteristics of restoration and tooth surfaces with a noncontact optical profilometer. The roughest surface was obtained with the diamond bur in all

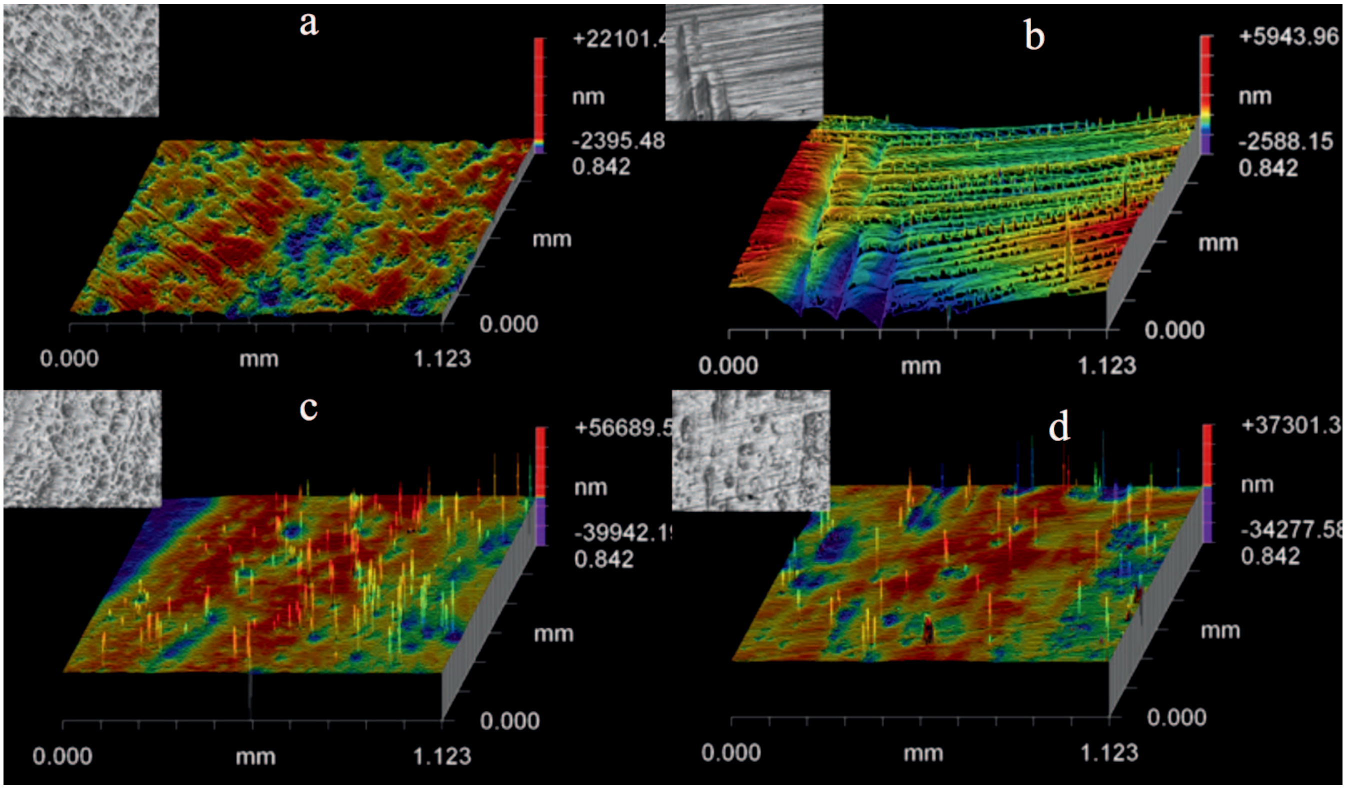


Figure 4. Three-dimensional oblique surface plots (interferograms) of a representative specimen from the monolithic-zirconia group conditioned with (a) Al_2O_3, (b) diamond bur, (c) Cojet, (d) HF acid. In each figure, the solid plot (left upper corner) depicts the surface texture when viewed perpendicularly.

groups. Representative interferograms are clearly indicative of the scratches over the material surfaces in a wavy pattern, when a diamond bur was used. Based on these findings, diamond bur, which applies a shearing force onto the surface, cannot be recommended for surface conditioning. The smoothest material surface was obtained with both HF acid and Cojet applications. Although a comparison of surface roughness parameters with other studies was not possible because of the lack of published data on 3D profilometry images of restoration surfaces, the findings obtained on the feldspathic porcelain surface were consistent with previous reports. Saraç et al.[25] compared the influence of HF acid etching and sandblasting on the porcelain surface roughness and found significant values that were close to each other. It was reported that a diamond bur and Al_2O_3 sandblasting obtained the highest roughness values, and in another study, the lowest roughness values were obtained by silicoating and HF acid etching on a porcelain surface.[26] The results of this study revealed that the highest Ra values for ceramic subgroups were obtained in the diamond bur and Al_2O_3 groups, followed by the HF acid group. It is crucial to state that conditioning the porcelain surface with Cojet resulted in almost the same surface roughness when compared with the unprocessed porcelain surface.

Sandblasting with either Al_2O_3 or Cojet did not cause excessive detrimental effects on the zirconia surface in this study. The Ra values of these applications were close to the original zirconia surface and can be considered safe. According to Sarmento et al.,[27] air abrasion with 110 μm Al_2O_3 resulted in higher roughness, but air-abrasion protocols with SiO_2 promoted better adhesion on a zirconia surface. The difference between Al_2O_3 and Cojet roughening on the monolithic zirconia surface was not significant in terms of the Ra value. However, the size of the sand particles and pressure of the devices may vary in different studies. Accordingly, the HF acid group had higher mean roughness values compared with Al_2O_3, which was consistent with other reports. When hybrid ceramic material is used, HF acid and Cojet techniques are more reliable methods in terms of occurrence of less degeneration in surface characteristics when compared with the unprocessed Enamic.

None of the applications were able to return the surface structures to their original condition. Nevertheless, comparisons between subgroups showed that surface characteristics that were most similar to their natural condition were obtained after roughening with

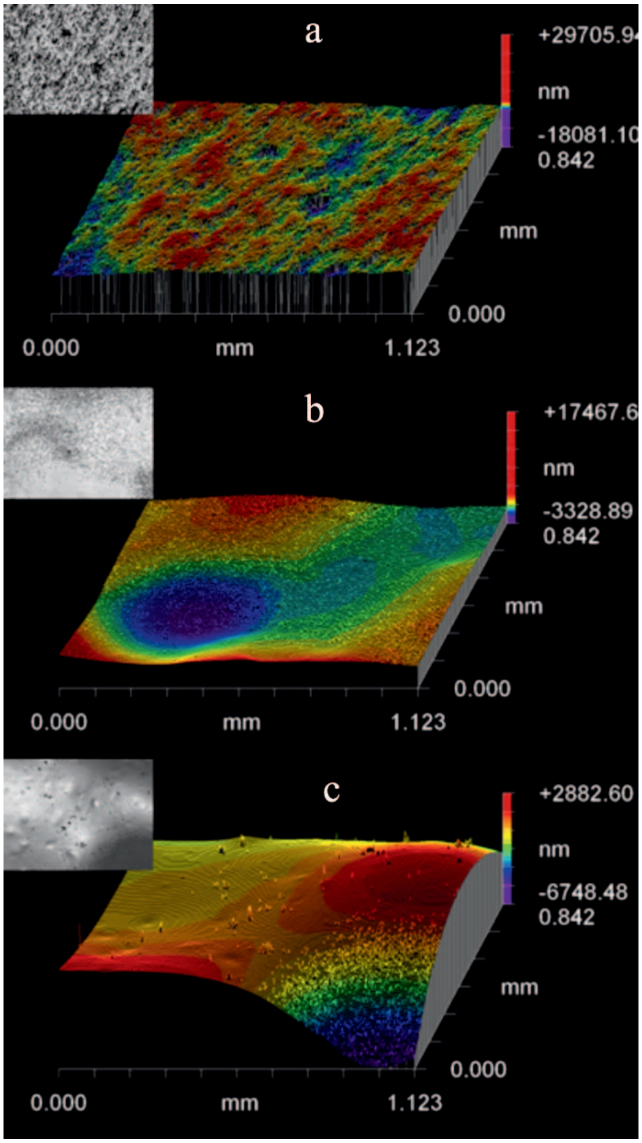


Figure 5. Three-dimensional oblique surface plots (interferograms) of a representative specimen of unprocessed raw material surface: (a) Enamic, (b) feldspathic porcelain, (c) monolithic zirconia. In each figure, the solid plot (left upper corner) depicts the surface texture when viewed perpendicularly.

Cojet or HF acid. Furthermore, it may be suggested that if intraoral sandblasting is to be performed for roughening, SiO_2 may be preferred over Al_2O_3. Surface-roughening methods analyzed in this study elicited different surface roughness findings, which in turn rejected the third and fourth hypotheses of the study.

When appropriate roughening and cleaning techniques are followed, an acceptable surface structure and bonding success can be obtained throughout treatment in patients with dental restorations. When both SBS and surface roughness characteristics of conditioning methods were taken into consideration, HF acid etching seemed to be the best technique based on the results obtained within the limitations of this study. However, clinicians should be aware of the possible hazardous effects of HF acid when used improperly.

CONCLUSIONS

- Variations of surface types of the materials affected the bonding resistance of orthodontic attachments. Comparisons of the materials with each other showed the highest bonding resistance to be for the feldspathic porcelain + HF acid group.
- Surface-roughening techniques affected the bonding resistance of the materials. In particular, material groups in which HF acid was applied had higher bonding resistance compared with the other subgroups. This conclusion should be interpreted with caution when the biosafety of the materials is considered.
- Variations in structures of the materials and roughening techniques affected the surface roughness findings. Examination of the surface roughness of all the unprocessed materials showed that none of the materials were able to return to their initial surface roughness values after debonding and polishing. The Ra values were significantly higher in all material groups in which a diamond bur was applied, while roughening with Cojet provided Ra values closer to the original material surface.
- All of the null hypotheses tested in this study were rejected.

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