Original Article

Surface Conditioning Methods and Polishing Techniques Effect on Surface Roughness of a Feldspar Ceramic

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ABSTRACT

Objective: To investigate the effects of three surface conditioning methods on shear bond strength (SBS) and on surface roughness (Ra) of a feldspathic ceramic, and to compare the efficiency of three polishing techniques.

Materials and Methods: A total of 106 feldspathic specimens were used. Thirty specimens were divided into three groups according to the surface conditioning methods: air-particle abrasion (APA) with 25-μm aluminum trioxide (Al_2O_3) (group A); hydrofluoric acid (HFA) (group H); APA and HFA (group AH). Metal brackets were bonded and subjected to SBS testing. Sixty-three specimens were divided into three groups according to the surface conditioning method. Ra was evaluated profilometrically. Then, each group was divided into three subgroups according to the polishing technique, ie, adjustment kit, diamond polishing paste, adjustment kit + diamond polishing paste. Following polishing, the second Ra values were obtained.

Results: The lowest SBS was obtained for group H. This value was significantly different from the values of groups A and AH ($P < .05$). The lowest Ra value was observed for group H ($P < .001$). There was no significant difference between groups A and AH ($P > .05$). No significant differences between the subgroups in which a polishing paste was used were observed ($P > .05$). There was no significant difference between the adjustment kit and the adjustment kit + a diamond polishing paste ($P > .05$).

Conclusion: APA or APA + HFA created rougher porcelain surfaces than HFA alone. Both adjustment kit use and the adjustment kit + polishing paste application were effective to smooth the porcelain, but one was not found superior to the other.

KEY WORDS: Surface conditioning; Polishing techniques; Surface roughness; Feldspathic porcelain

INTRODUCTION

A more demanding sense of esthetics has led to an increase in adults requesting orthodontic treatment. Thus, the orthodontist frequently encounters all-ceramic restorations, which are gaining popularity because of their superior biocompatibility and distinct esthetic appeal.[1] The conventional orthodontic bonding system does not guarantee enough adhesion to porcelain to withstand orthodontic forces. Thus, to increase the bond strength of orthodontic brackets to porcelain restorations, several options that are generally combinations of various mechanical and chemical conditioning methods are available. These methods are bonding to glazed porcelain with a coupling agent (silane), deglazing the porcelain by roughening the surface with diamond burs, air-particle abrasion (APA) with aluminum oxide, and chemical preparation of the porcelain with acids (phosphoric acid, hydrofluoric acid [HFA], or acidulated phosphate fluoride).[2–6]

Surface conditioning roughens the porcelain for the formation of appropriate micromechanical bonds between the porcelain and the resin.[7] Limited research concerning the measurement of surface roughness (Ra) of all-ceramic materials following surface conditioning to increase bond strength for orthodontic bond-

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ing exists.[2] Schmage et al[2] demonstrated higher Ra and higher bond strength with APA using 50-μm aluminum trioxide (Al_2O_3) (9.7 μm and 15.8 MPa, respectively) than with HFA alone (4.3 μm and 12.2 MPa, respectively).

Roughening the porcelain may cause a reduction in the strength of the porcelain restoration.[8] Furthermore, the roughened porcelain may cause an increased rate of plaque accumulation, thus producing gingival inflammation and adverse soft tissue reactions.[9] Damage to the porcelain caused by roughening during surface conditioning should be minimized, because these restorations ordinarily remain in the mouth following orthodontic treatment.[3] Nevertheless, in order to obtain a viable bond between the bracket and the porcelain, mechanical or chemical roughening is mandatory.[2,3,6,10]

For these reasons, the roughened porcelain has to be reglazed or, alternatively, polished after orthodontic treatment. Subjecting the porcelain to another firing cycle is time-consuming and has the potential of adversely changing the porcelain structure, like devitrification.[11] Besides, reglazing necessitates the removal of the restoration from the prepared tooth, and this procedure may be damaging to the restoration as well as to the tooth.

After debonding, different polishing procedures of porcelain have been described.[12–16] Different results have been obtained concerning the effectiveness of polishing. Diamond polishing paste was reported to restore the surface to its original appearance.[12–15] However, Zelos et al[16] stated that the use of an adjustment kit + diamond glaze polish presented an almost ideal finish.

The aims of this study were (1) to investigate the effects of surface conditioning on the shear bond strength (SBS) of metal brackets, (2) to investigate the effect of surface conditioning on Ra of a feldspathic ceramic, and (3) to compare the efficiency of polishing techniques applied after surface conditioning using a profilometer and a field emission scanning electron microscope (SEM).

MATERIALS AND METHODS

One hundred six feldspathic (Vitadur Alpha; Vita Zahnfabrik, Bad Säckingen, Germany) porcelain specimens (10 × 10 × 3 mm) were fabricated and glazed according to the manufacturer's specifications.

Shear Bond Strength Test

Thirty porcelain specimens were mounted with autopolymerizing acrylic resin (Meliodent; Heraeus Kulzer Ltd, Newbury, Berkshire, UK) and were randomly divided into three groups (n = 10) according to the surface conditioning methods: group A, APA with 25-μm Al_2O_3 via an air abrasion device (Bego TopTec; Bego, Bremen, Germany) from a distance of approximately 10 mm at a pressure of 2.5 bars for 4 seconds; group H, etching with 9.6% HFA gel (Porcelain Etch Gel; Pulpdent, Watertown, Mass) for 2 minutes; and group AH, APA + HFA application as described for groups A and H, respectively.

All the specimens were washed, rinsed, and air-dried. Silane (Bond Enhancer; Pulpdent) and subsequently an adhesive primer (Transbond™ XT; 3M Unitek, Monrovia, Calif) were applied to the porcelain. A light-cure microfilled resin (Transbond™ XT; 3M Unitek) was applied to the mesh base of a maxillary central incisor bracket (Gemini bracket; 3M Unitek). The bracket was seated and positioned manually. Excess composite was removed. The adhesive paste was cured for a total of 20 seconds from two directions using a visible light-curing unit with an output of 600 mW/cm^2. All specimens were stored in distilled water at 37 ± 2°C for 1 week. The specimens were thermocycled 500 times between 5°C and 55°C with a dwelling time of 30 seconds. The shear bond test was performed with a universal testing device (Lloyd LRX; Lloyd Instruments Ltd, Fareham, Hants, UK) at a crosshead speed of 1 mm/min. The bond strengths were calculated in megapascals.

The porcelain surfaces were examined with a stereomicroscope (Stemi 2000-C; Carl Zeiss, Göttingen, Germany) at a magnification of 10× to determine the amount of composite resin according to the adhesive remnant index[17] and to assess porcelain damage that might have occurred during shear bond testing.

Furthermore, one intact glazed and three surface-conditioned specimens (APA, HFA, and APA + HFA) were examined under an SEM (JSM-6335F; Jeol, Tokyo, Japan) at 15.0 kV. SEM photomicrographs were taken at 500× magnifications for visual inspection.

Ra Test

Sixty-three specimens were randomly divided into three groups (n = 21) according to surface conditioning. Subsequently, the Ra was evaluated with a profilometer (Surftest 402; Mitutoyo Co, Kanagawa, Japan).

The profilometer was calibrated using a standard reference specimen, then set to travel at a speed of 0.100 mm/s with a range of 600 μm during testing. To measure the Ra value, the diamond stylus (5-μm tip radius) was moved across the surface under a constant load of 3.9 mN. The surface analyzer was used to determine the roughness profile of each specimen. This procedure was repeated three times, and the average value was considered to be the first Ra value. These values were used to compare the Ra of the

Table 1. Mean Shear Bond Strength Values (MPa) for Surface Conditioning Methods

Group	Mean[a]	SD
A	17.90 A	3.22
H	5.39 B	2.59
AH	20.37 A	3.02

[a] Same letters indicate groups that were not statisically different ($P > .05$).

Table 2. One-Way Analysis of Variance Results for Shear Bond Strength Test

	Sum of Squares	*df*	Mean Square	F	Significance
Between groups	1290.07	2	645.03	73.85	0.000
Within groups	235.84	27	8.74		
Total	1525.91	29			

Table 3. Mean Ra Values for Surface Conditioning Methods and Polishing Techniques[a]

Group	n	Mean (SD)[b]	Subgroup	n	Mean (SD)[b]
A	21	3.90 (0.27) A	AK	7	1.88 (0.24) A
			AP	7	0.19 (0.10) D
			AKP	7	1.42 (0.24) A
H	21	2.22 (0.13) B	HK	7	0.57 (0.13) BD
			HP	7	0.33 (0.09) D
			HKP	7	0.75 (0.18) B
AH	21	4.02 (0.30) A	AHK	7	2.19 (0.22) C
			AHP	7	0.21 (0.14) D
			AHKP	7	2.70 (0.17) C

[a] RA indicates surface roughness.

[b] Same letters indicate groups that were not statistically different ($P > .05$).

Table 4. One-Way Analysis of Variance Results of Surface Roughness for Surface Conditioning Methods

	Sum of Squares	*df*	Mean Square	F	Significance
Between groups	42.553	2	21.276	361.993	0.000
Within groups	3.527	60	0.059		
Total	46.079	62			

conditioning methods and were analyzed by 1-way analysis of variance (SPSS 12.0; SPSS Inc, Chicago, IL, USA). The mean Ra values were compared with the post hoc Tukey multiple comparison test ($\alpha = .05$).

Following the profilometric analysis, each group was divided into three subgroups ($n = 7$) according to the polishing techniques: adjustment kit (Shofu Dental GmbH, Ratingen, Germany; subgroups AK, HK, and AHK), diamond polishing paste (Diamond Stick, Shofu Dental GmbH, Ratingen, Germany; subgroups AP, HP, and AHP) and adjustment kit + diamond polishing paste (subgroups AKP, HKP, and AHKP).

Polishing was performed until the surface appeared shiny to the naked eye, simulating clinical procedures. After the polishing, the second Ra values were obtained. The Ra mean difference (ΔRa) for each specimen was calculated by subtracting the mean second reading from the mean first reading. Therefore, a positive mean difference in ΔRa would represent an increase in smoothness and the larger the value, the greater the smoothness. The ΔRa values were analyzed by 2-way analysis of variance to obtain the significant differences among surface conditioning, polishing techniques, and their interactions. All treatment combination means for Ra (ΔRa) were compared with the post hoc Tukey multiple comparison test ($\alpha = .05$).

For SEM evaluation, the surfaces of an additional nine specimens were roughened with the surface conditioning methods and subjected to the polishing techniques. These polished specimens were examined under the SEM at 15.0 kV. The SEM photomicrographs were taken with 500$\times$ magnification for visual inspection.

RESULTS

Mean SBS values and comparison of the groups are given in Table 1. SBS was significantly affected by surface conditioning ($P < .001$; Table 2). The lowest SBS value was obtained for group H (5.39 MPa), and this value was significantly different from the values of the other groups ($P < .05$; Table 1). No significant difference was found between groups A and AH ($P > .05$). The adhesive failures occurred between the porcelain and composite resin in all groups, ie, there were no adhesive remnants on the porcelain surface. Cracks or fractures of the porcelain were not observed.

The mean Ra values and the comparisons of the groups are presented in Table 3. The Ra was significantly affected by the surface conditioning ($P < .001$; Table 4). The lowest Ra value was observed for group H, and this value was significantly different from the values for groups A and AH ($P < .001$). There was no significant difference between groups A and AH ($P > .05$).

The mean ΔRa values and the comparisons of the subgroups are presented in Table 3. The surface conditioning and the polishing techniques affected the Ra values of the specimens significantly ($P < .001$; Table 5). For polishing techniques, it was shown that there was no significant difference between the subgroups that were polished with the paste alone (subgroups AP, HP, and AHP; $P > .05$). Also, there was no significant difference between the use of an adjustment kit and an adjustment kit + polishing paste for each surface conditioning method ($P > .05$).

When the SEM photomicrographs were examined,

Table 5. Two-Way Analysis of Variance Results for Surface Conditioning Methods and Polishing Techniques

Source	Sum of Squares	df	Mean Square	F	Significance
Surface conditioning	13.87	2	6.937	254.90	0.000
Polishing technique	25.26	2	12.628	464.01	0.000
Surface conditioning × polishing technique	10.27	4	2.567	94.31	0.000
Error	1.47	54	0.027		
Corrected total	50.87	62	6.937		

groups A and AH displayed rougher surfaces than group H (Figure 1). When the effects of the polishing techniques were examined, the use of an adjustment kit + polishing paste and an adjustment kit alone presented smoother surfaces than did the polishing paste alone (Figure 2).

DISCUSSION

Clinically adequate bond strength for a metal orthodontic bracket to enamel should range from 6 to 8 MPa.[18] All SBS values in the present study were above this optimal range, rendering them clinically acceptable, except for the value obtained with the use of HFA alone. In the present study, the lowest SBS value was found with HFA. Nevertheless, chemical roughening with HFA has been reported to be effective for improving bond strengths.[6,10] No significant difference was found for SBS between groups A and AH. These values were higher than the SBS value produced by HFA. Disagreement exists concerning the effectiveness of APA with Al_2O_3 particles: APA with Al_2O_3 particles was more effective than chemical etching with HFA.[2] However, in some studies no significant difference was reported between APA and chemical etching.[19] APA roughens the ceramic surface by particle removal, whereas HFA roughens the ceramic surface by dissolving the crystalline and the glassy phases of the ceramic.[3] Because of this, mechanical surface conditioning seems to be more effective than chemical conditioning. On the other hand, Al_2O_3 particle size, concentration, type of acid, and application period all affect the degree of Ra.

In all samples, adhesive failures between the porcelain and composite resin were seen. This type of adhesive failure demonstrated that the bond strength between the composite and the bracket and the cohesive strength of the composite were stronger than the bond strength between the composite and the porcelain. Smith et al[4] stated that this type of adhesive failure is desirable, because the problem of residual composite is not encountered. Adhesive failures at the porcelain/composite interface are preferred to avoid porcelain fractures during debonding.[4] It has been reported that if bond strengths between the porcelain and the composite resin are higher than 13 MPa, cohesive failures are observed in the porcelain.[20] In the present study, most of the groups had values higher than 13 MPa, which resulted in adhesive failures. Porcelain fractures or cracks were not observed. These findings agree with the results of Harari et al,[6] who reported adhesive failure for H and APA groups. This observation is clinically important because a lack of macroscopic damage to the porcelain surface indicates the long-term integrity of the restoration.[6]

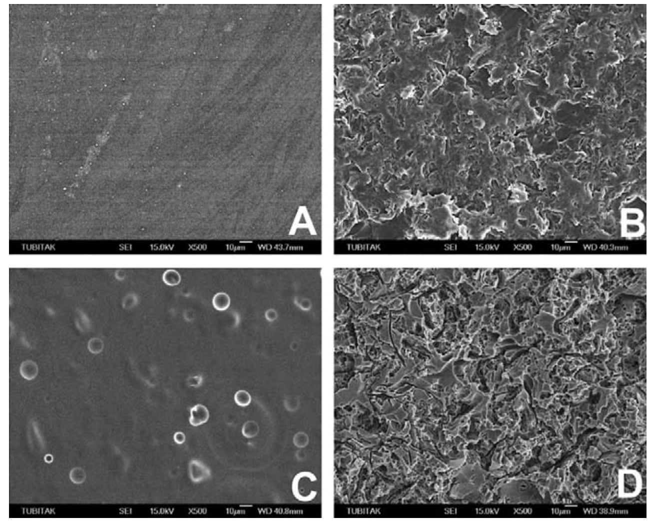

Figure 1. Scanning electron photomicrographs of feldspathic ceramic (500×): (A) Intact ceramic. (B) APA application. (C) HFA application. (D) APA + HFA application.

Chemical roughening with HFA showed more unchanged glazed surfaces and fewer pits. Mechanical roughening with Al_2O_3 displayed loss of the glazed surface and an erosive appearance with shallow penetration and undercuts. Mechanical and chemical roughening with APA + HFA demonstrated deep grooves and pronounced undercuts. These different photomicroscopic appearances corroborate the SBS values. The bond strength gradually increased because of the gradual increase in roughening of the porcelain. However, this gradual increase of bond strength and of Ra was not statistically significant between group A and group AH. HFA application after APA did not display an advantage over APA application alone. Therefore, one might prefer APA alone because of the potential harmful and irritating effects of HFA.

Higher Ra values were obtained with APA (3.9 μm) and APA + HFA (4.0 μm) than with HFA (2.2 μm) alone. This result was verified by the SEM photomicrographs. Schmage et al[2] also demonstrated higher Ra with APA (9.7 μm) than with HFA (4.3 μm). HFA is applied to increase micromechanical retention, creating surface pits by preferential dissolution of the

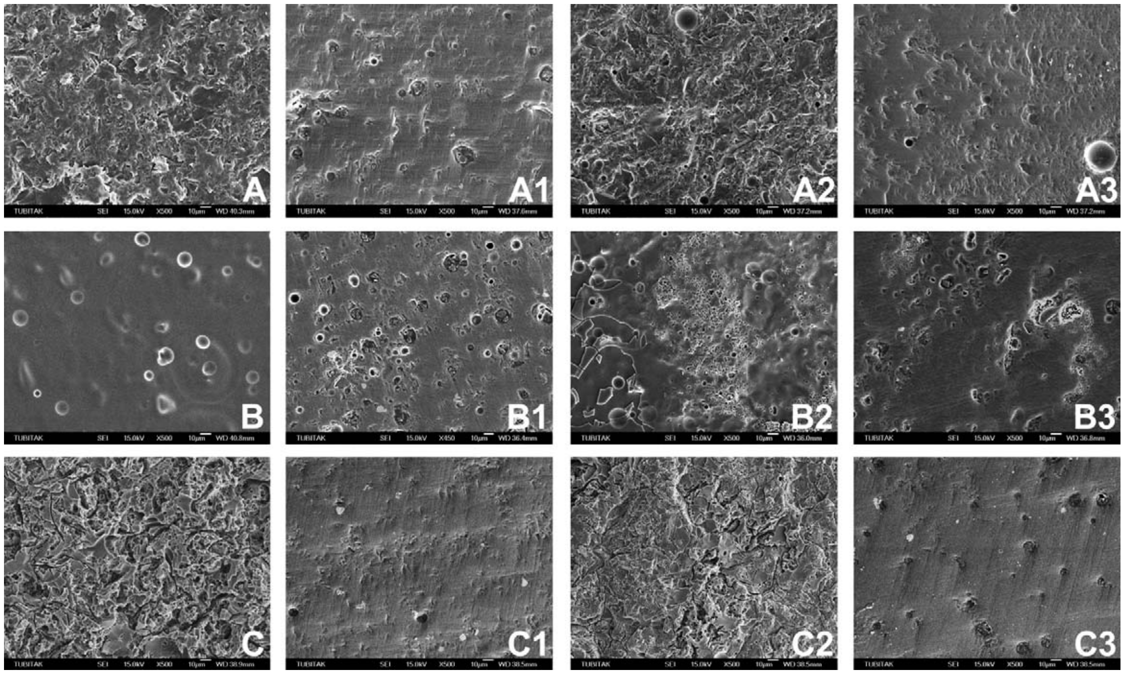

Figure 2. Scanning electron photomicrographs of feldspathic ceramic (500×): (A) APA application. (A1) Adjustment kit. (A2) Polishing paste. (A3) Adjustment kit+paste. (B) HFA application. (B1) Adjustment kit. (B2) Polishing paste. (B3) Adjustment kit + paste. (C) APA + HFA application. (C1) Adjustment kit. (C2) Polishing paste. (C3) Adjustment kit + paste.

glass phase from the ceramic matrix, and to acidify the porcelain before silane application.[20] The high aluminum oxide–containing glaze makes it more resistant to chemical attack and reduces the effect of HFA etching.[5]

After orthodontic treatment, chairside porcelain polishing is an important consideration for the lifetime of the restoration. Based on SEM and photomicrograph results, several studies have reported that polishing can produce surfaces as smooth as the original glaze.[12–15] Winchester[12] stated that the evaluation of smoothness of porcelain surfaces from photomicrographs is very difficult and subjective. Jarvis et al[21] evaluated Ra with a profilometer to observe whether restoration of the surface to the prebond condition was possible.

In the present study, it was observed that the polishing paste did not significantly improve the smoothness of the porcelain. The Ra values obtained with polishing paste were found to be significantly different than Ra values obtained with the adjustment kit and the adjustment kit + diamond polishing paste. Hulterstrom and Bergman[22] and Zelos et al[16] reported similar findings. Thus, a polishing paste per se is not effective. The success of the adjustment kit can be attributed to the abrasive stones and wheels of the kit. The abrasive particles are hard enough to remove the irregularities from the porcelain. The different polishing techniques used in the present study were chosen because they have been recommended as quick, efficient polishing systems with a minimum of work stages. Even though polishing procedures smooth the roughened porcelain surfaces, a restoration to the original condition does not seem possible. The SEM photomicrograph corroborates this statement. Also, Jarvis et al[21] found that polishing procedures did not restore the surface of the porcelain to its prebonding state.

CONCLUSIONS

- SBS values were found to be above the optimal range (6–8 MPa), except for the feldspathic ceramic treated with HFA.
- APA alone or APA + HFA created rougher porcelain surfaces than HFA alone.
- HFA application after APA did not display an advantage over APA alone for bond strength and for Ra.
- Use of either the adjustment kit alone or the adjustment kit + polishing paste was found to be effective to smooth the porcelain surfaces, but neither method was found to be superior to the other. Application of the polishing paste alone did not improve the smoothness of the ceramic.

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