European Journal of Orthodontics 28 (2006) 450–456
doi:10.1093/ejo/cjl010
Advance Access publication 13 June 2006

Effects of surface conditioning on bond strength of metal brackets to all-ceramic surfaces

Tamer Türk*, Duygu Saraç**, Y. Şinasi Saraç** and Selma Elekdağ-Türk*
Departments of *Orthodontics and **Prosthodontics, Faculty of Dentistry, University of Ondokuz Mayıs, Turkey

SUMMARY The aim of this study was to determine the effectiveness of bonding brackets to ceramic restorations. Sixty feldspathic and 60 lithium disilicate ceramic specimens were randomly divided into six groups. Shear bond strength (SBS) and bond failure types were examined with six surface-conditioning methods: silane application to glazed surface, air particle abrasion (APA) with 25- and 50-μm aluminium trioxide (Al_2O_3), etching with 9.6 per cent hydrofluoric acid (HFA), and roughening with 40- and 63-μm diamond burs. Silane was applied to all roughened surfaces. Metal brackets were bonded with light cure composite, then stored in distilled water for 1 week and thermocycled (×500 at 5–55°C for 30 seconds). The ceramic surfaces were examined with a stereomicroscope at a magnification of ×10 to determine the amount of composite resin remaining using the adhesive remnant index.

The lowest SBS values were obtained with HFA for feldspathic (5.39 MPa) and lithium disilicate (11.11 MPa) ceramics; these values were significantly different from those of the other groups. The highest SBS values were found with 63-μm diamond burs for feldspathic (26.38 MPa) and lithium disilicate (28.20 MPa) ceramics, and were not significantly different from 40-μm diamond burs for feldspathic and lithium disilicate ceramics (26.04 and 24.26 MPa, respectively). Roughening with 25- and 50-μm Al_2O_3 particles showed modest SBS for lithium disilicate (22.60 and 26.15 MPa, respectively) and for feldspathic ceramics (17.90 and 14.66 MPa, respectively). Adhesive failures between the ceramic and composite resin were noted in all groups. Damage to the porcelain surfaces was not observed.

The SBS values were above the optimal range, except for feldspathic ceramic treated with HFA and silane. With all surface-conditioning methods, lithium disilicate ceramic displayed higher SBS than feldspathic ceramic.

Introduction

In recent years there has been an increase in the number of adults seeking orthodontic treatment. Therefore, the orthodontist is often faced with the challenge of effectively bonding orthodontic brackets to ceramic restorations in adult patients.

All-ceramic dental materials are gaining popularity due to their superior biocompatibility and aesthetic appeal (Albakry *et al.*, 2004). Furthermore, all-ceramic materials demonstrate a great deal of diversity due to recent advances in restorative material technology (Wen *et al.*, 1999; Guazzato *et al.*, 2002).

Pre-treatment of ceramic surfaces is necessary to obtain sufficient strength to bond orthodontic brackets to all-ceramic restorations. Several options have been described which are generally combinations of various mechanical and chemical conditioning methods, such as bonding to glazed ceramic with a coupling agent (silane), deglazing the ceramic by roughening the surface [diamond burs; air particle abrasion (APA) with aluminium oxide], and chemical preparation of the ceramic with acids, such as phosphoric, hydrofluoric, acidulated phosphate fluoride (Eustaquio *et al.*, 1988; Kao *et al.*, 1988; Smith *et al.*, 1988; Winchester, 1991; Zachrisson and Büyükyılmaz, 1993; Whitlock *et al.*, 1994; Zelos *et al.*, 1994; Barbosa *et al.*, 1995; Major *et al.*, 1995; Zachrisson *et al.*, 1996; Cochran *et al.*, 1997; Gillis and Redlich, 1998; Bourke and Rock, 1999; Sant'Anna *et al.*, 2002; Harari *et al.*, 2003; Pannes *et al.*, 2003; Özcan *et al.*, 2004).

It has been shown that silane coupling agents appear to enhance the bond strength by increasing the chemical bond between the resin composite and ceramic material (Wood *et al.*, 1986; Kao and Johnston, 1991; Cochran *et al.*, 1997; Chung *et al.*, 1999; Huang and Kao, 2001; Kocadereli *et al.*, 2001; Schmage *et al.*, 2003). The silica of the ceramic is chemically joined with the acrylic group of the composite resin through silanization (Zachrisson *et al.*, 1996; Schmage *et al.*, 2003).

It has been demonstrated that silane enhances the bonding of brackets to glazed ceramic surfaces, but that the bond strengths achieved might not be adequate for clinical orthodontics (Newman *et al.*, 1984; Eustaquio *et al.*, 1988; Zelos *et al.*, 1994; Barbosa *et al.*, 1995; Nebbe and Stein, 1996; Sant'Anna *et al.*, 2002; Pannes *et al.*, 2003). In general, the silane coupling agent is applied with chemical and mechanical roughening procedures (Wood *et al.*, 1986;

Major *et al.*, 1995; Gillis and Redlich, 1998; Chung *et al.*, 1999; Huang and Kao, 2001; Kocadereli *et al.*, 2001; Schmage *et al.*, 2003; Özcan *et al.*, 2004).

Etching the ceramic surfaces with acids followed by the application of a ceramic primer and a bonding agent are advised procedures (Zachrisson and Büyükyılmaz, 1993; Cochran *et al.*, 1997; Bourke and Rock, 1999; Chung *et al.*, 1999; Huang and Kao, 2001; Özcan *et al.*, 2004). However, the harmful effect of hydrofluoric acid (HFA) on the soft tissues has been highlighted (Barbosa *et al.*, 1995; Bourke and Rock, 1999; Schmage *et al.*, 2003; Özcan *et al.*, 2004).

Mechanical roughening with diamond burs and APA has been shown to provoke crack initiation on the ceramic surface (Peterson *et al.*, 1998). Damage to the ceramic due to roughening during surface conditioning should be minimized since the restorations ordinarily remain in the mouth following orthodontic treatment (Schmage *et al.*, 2003). However, in order to obtain a viable bond between the orthodontic bracket and the ceramic surface, mechanical or chemical roughening is inevitable (Wood *et al.*, 1986; Kao *et al.*, 1988; Barbosa *et al.*, 1995; Gillis and Redlich, 1998; Huang and Kao, 2001; Kocadereli *et al.*, 2001; Harari *et al.*, 2003; Pannes *et al.*, 2003; Schmage *et al.*, 2003; Özcan *et al.*, 2004).

Only a limited number of studies exist concerning the bond strength of orthodontic brackets to all-ceramic restorations, and in most of these, feldspathic ceramic was mainly used (Pannes *et al.*, 2003; Schmage *et al.*, 2003; Özcan *et al.*, 2004). Furthermore, insufficient information exists concerning the bond strength of other all-ceramic materials to orthodontic brackets.

The objectives of this study were to observe the outcomes of six different surface-conditioning methods on the shear bond strength (SBS) of metal orthodontic brackets to two different all-ceramic restorative materials (feldspathic and lithium disilicate) and to evaluate the mode of failure after debonding.

Materials and methods

Sixty feldspathic (Vitadur Alpha; Vita Zahnfabrik, Bad Säckingen, Germany) and 60 lithium disilicate (Empress 2; Ivoclar Vivadent, Schaan, Liechtenstein) ceramic specimens with a diameter of 6 mm and a thickness of 3 mm were fabricated and glazed according to the manufacturers' recommendations. The specimens were embedded in autopolymerizing acrylic resin blocks (Meliodent; Heraeus Kulzer Ltd, Newbury, Berkshire, UK) with their glazed surfaces facing upwards. For each all-ceramic material, the specimens were randomly divided into six groups, each containing 10 specimens and six different surface-conditioning methods were used. The groups and the surface-conditioning methods are shown in Table 1.

The sample size was based upon previous studies. In the majority of these studies the sample size ranged from 5 to 10 specimens (Kern and Thompson, 1994; Whitlock *et al.*, 1994; Zelos *et al.*, 1994; Major *et al.*, 1995; Nebbe and Stein, 1996; Gillis and Redlich, 1998; Bourke and Rock, 1999; Huang and Kao, 2001; Kocadereli *et al.*, 2001; Pannes *et al.*, 2003; Schmage *et al.*, 2003; Özcan *et al.*, 2004).

Table 1 Characteristics of the six surface-conditioning methods.

Groups	Conditioning methods
Silane	Silane application to glazed surface
Al_2O_3, 25 μm + silane	Al_2O_3, 25 μm, 4 seconds at a pressure of 2.5 bars + silane
Al_2O_3, 50 μm + silane	Al_2O_3, 50 μm, 4 seconds at a pressure of 2.5 bars + silane
Hydrofluoric acid + silane	9.6% hydrofluoric acid, 2 minutes + silane
Extra-fine bur + silane	Extra-fine diamond bur, 40 μm + silane
Fine bur + silane	Fine diamond bur, 63 μm + silane

Silane (Bond Enhancer; Pulpdent, Watertown, Massachusetts, USA) was applied to the specimens in the first group without any roughening procedures. In the second group, APA was performed using 25 μm aluminium trioxide (Al_2O_3) with an air abrasion device (Bego TopTec; Bego, Germany) at a distance of approximately 10 mm and a pressure of 2.5 bars for 4 seconds. In the third group, APA was carried out using 50 μm Al_2O_3 under the same conditions. In the fourth group, the ceramic surfaces were etched with 9.6 per cent HFA gel (Porcelain Etch Gel; Pulpdent) for 2 minutes. In the fifth and sixth groups, mechanical roughening was performed with fine (63 μm, Medin, Nové Město na Moravě, Czech Republic) and extra-fine (40 μm, Medin) diamond burs. The cylindrical diamond burs, with their shafts parallel to the specimens, were rotated at 40 000 rpm. After chemical and mechanical roughening, the specimens were washed and rinsed thoroughly to remove the debris and then air-dried. Subsequently, silane and the adhesive primer (Transbond™ XT; 3M Unitek, Monrovia, California, USA) were applied to all roughened specimens. The light cure adhesive paste (Transbond™ XT; 3M Unitek) was applied to the mesh base of a maxillary central incisor bracket (Gemini bracket; 3M Unitek). Subsequently, the bracket was seated and positioned manually on the ceramic surface. Excess composite was carefully removed from the periphery of the bracket base with an explorer. The surface-conditioning methods and the placement of the brackets were performed by one operator (TT). The adhesive paste was cured for a total of 20 seconds from two directions using a visible light-curing unit (Hilux 200; Benlioglu Dental Inc., Ankara, Turkey) 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 in a custom-made device (Nova Inc., Konya, Turkey) 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/minute. The bond strengths were calculated in megapascals (MPa).

The ceramic 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 remaining according to the adhesive remnant index (Årtun and Bergland, 1984) and to assess the damage to the ceramic which may have occurred during shear bond testing.

To evaluate the effect of surface-conditioning methods on the ceramic surfaces, six additional feldspathic and six lithium disilicate ceramic specimens were prepared and glazed. The surfaces of five specimens of each ceramic were then conditioned with the same experimental protocol described above. The intact glazed and the five roughened samples for each ceramic were gold sputtered with a sputter coater (S150B; Edwards, Crawley, Sussex, UK) and examined under a field emission scanning electron microscope (SEM, JSM-6335F; Jeol, Tokyo, Japan) at 15.0 kV. The SEM photomicrographs were taken at ×500 magnification for visual inspection.

Two-way analysis of variance for (2 × 2) × 10 factorial design was performed to determine significant differences among porcelain surface conditioning, porcelain types, and their interactions. All treatment combination means for SBS values were compared using the Tukey multiple comparison test ($\alpha = 0.05$).

Results

Mean SBS, minimum and maximum values, and standard deviations for each group, except the first group due to debonding of the brackets during thermocycling, are given in Table 2. The main effects were significant differences for the conditioning methods and ceramic types on the SBS values ($P < 0.05$; Table 3). There was also a significant interaction between the conditioning methods and ceramic. The results of the Tukey multiple comparison test to compare the mean SBS values are given in Table 2.

The lowest SBS was with HFA for the feldspathic ceramic (5.39 MPa) which was not significantly different from HFA for the lithium disilicate ceramic (11.11 MPa). These values were, however, significantly different from the values of the other groups with one exception: the SBS of HFA in the lithium disilicate ceramic was not significantly different from the SBS (14.66 MPa) of APA with 50-μm Al_2O_3 for the feldspathic ceramic.

The highest SBS values were obtained using the fine diamond bur with the feldspathic and lithium disilicate ceramics (26.38 and 28.20 MPa, respectively) and were not significantly different from the SBS obtained with the

Table 2 Mean shear bond strengths (*X*), minimum (Min) and maximum (Max) values, and standard deviations (SD) for each group ($n = 10$).

Types of ceramic	Groups	*X*	SD	Min	Max	Homogeneous subsets
Feldspathic	Al_2O_3, 25 μm + silane	17.90	3.22	14.05	22.91	CD
	Al_2O_3, 50 μm + silane	14.66	3.17	10.05	19.94	BC
	Hydrofluoric acid + silane	5.39	2.59	2.68	9.80	A
	Extra-fine bur + silane	26.04	5.71	17.51	32.64	E
	Fine bur + silane	26.38	4.96	18.78	34.24	E
Lithium disilicate	Al_2O_3, 25 μm + silane	22.60	2.53	19.30	27.01	DE
	Al_2O_3, 50 μm + silane	26.15	6.70	14.08	35.17	E
	Hydrofluoric acid + silane	11.11	4.07	5.98	17.03	AB
	Extra-fine bur + silane	24.26	4.87	18.52	33.64	E
	Fine bur + silane	28.20	3.63	19.75	31.60	E

Means for groups having the same letters show homogeneous subsets. $\alpha = 0.05$.

Table 3 Two-way analysis of variance of force (mega pascals) required to debond metal brackets from dental ceramic.

Source of variation	Mean square	df	Sum of squares	*F* ratio	Significance
Ceramic	481.837	1	481.837	25.485	0.000
Surface conditioning	4352.353	4	1088.088	57.551	0.000
Ceramic × surface conditioning	484.002	4	121.001	6.400	0.000
Error	1701.571	90	18.906		
Corrected total	7019.763	99			

extra-fine diamond bur for the feldspathic and lithium disilicate ceramics (26.04 and 24.26 MPa, respectively).

APA with Al_2O_3 particles showed, in general, modest SBS for both ceramics. The SBS values obtained using APA with 25- and 50-μm Al_2O_3 particles (22.60 and 26.15 MPa, respectively) and lithium disilicate ceramic were not significantly different from those obtained with the diamond burs. The SBS obtained with APA and 25- and 50-μm Al_2O_3 particles (17.90 and 14.66 MPa, respectively) for the feldspathic ceramic showed a significant difference from the SBS obtained with the diamond burs. Roughening by APA with 25 μm Al_2O_3 particles of both ceramics was not significantly different from each other.

The modes of bond failure for the brackets after different surface-conditioning methods are given in Table 4. Adhesive failures between the ceramic and composite resin were observed in all groups. Cracks or fractures of the ceramic surfaces were not observed.

The scanning electron photomicrographs of feldspathic and lithium disilicate ceramic surfaces conditioned using different methods are presented in Figures 1 and 2, respectively. The glazed surfaces of the two ceramics had a smooth appearance (Figures 1A and 2A). APA with 25- and 50-μm Al_2O_3 particles demonstrated mild roughening of the surface (Figures 1B, 2B and 1C, 2C, respectively). HFA etching produced minimal change and did not appear to alter the glazed porcelain surfaces (Figures 1D and 2D). Roughening with extra-fine and fine diamond burs showed deep grooves (Figures 1E, 2E and 1F, 2F, respectively).

Discussion

The aim of this study was the evaluation of the effectiveness of different surface-conditioning methods on the SBS of metal orthodontic brackets to two different all-ceramic restorative materials (feldspathic and lithium disilicate). Clinically adequate bond strength for a metal orthodontic bracket to enamel should range from 6 to 8 MPa (Reynolds, 1975). All SBS values in the present study were above this optimal range, rendering them clinically acceptable, except for feldspathic ceramic treated with HFA and silane.

Samples coated with silane, but not exposed to chemical or mechanical roughening, were considered as the control group but demonstrated bond failures during thermocycling. Barbosa *et al.* (1995) reported the premature loss of brackets bonded to glazed ceramic surfaces coated with silane after 7 days of water immersion. They explained that this premature loss was due to the high solubility of silane in water. Likewise, all specimens were stored in distilled water for 1 week in the present investigation. Furthermore, the relationship between silane and the glazed surface might be affected by the glaze composition. The glaze materials containing high alumina, as used in the present study, affect the chemical reaction between silane and ceramic. Silane will not enhance the bond to ceramic that contains only a small amount of silica (Kern and Thompson, 1994; Zachrisson *et al.*, 1996). The premature loss of brackets confirms that bonding to glazed surfaces coated with silane does not provide adequate bond strength and that silane coating should be combined with surface roughening (Wood *et al.*, 1986; Kao *et al.*, 1988; Smith *et al.*, 1988; Zachrisson and Büyükyılmaz, 1993; Barbosa *et al.*, 1995; Zachrisson *et al.*, 1996; Huang and Kao, 2001; Kocadereli *et al.*, 2001; Harari *et al.*, 2003; Pannes *et al.*, 2003; Özcan *et al.*, 2004).

In the present study the silane application was combined with mechanical or chemical roughening to increase SBS. Silane application following surface roughening provides a statistically significant increase in SBS (Wood *et al.*, 1986; Kao *et al.*, 1988; Smith *et al.*, 1988; Kao and Johnston,

Table 4 Modes of failure of metal brackets bonded to two all-ceramics after six surface-conditioning methods.

Types of ceramic	Groups	Adhesive remnant index score				
		Debonded*	0	1	2	3
Feldspathic	Silane	10	—	—	—	—
	Al_2O_3, 25 μm + silane	—	10	—	—	—
	Al_2O_3, 50 μm + silane	—	10	—	—	—
	Hydrofluoric acid + silane	—	10	—	—	—
	Extra-fine bur + silane	—	10	—	—	—
	Fine bur + silane	—	10	—	—	—
Lithium disilicate	Silane	10	—	—	—	—
	Al_2O_3, 25 μm + silane	—	10	—	—	—
	Al_2O_3, 50 μm + silane	—	10	—	—	—
	Hydrofluoric acid + silane	—	10	—	—	—
	Extra-fine bur + silane	—	10	—	—	—
	Fine bur + silane	—	10	—	—	—

Score 0 = no composite left on the ceramic surface; score 1 = less than half of the composite left; score 2 = more than half of the composite left; score 3 = all composite left on the ceramic surface.*During thermocycling.

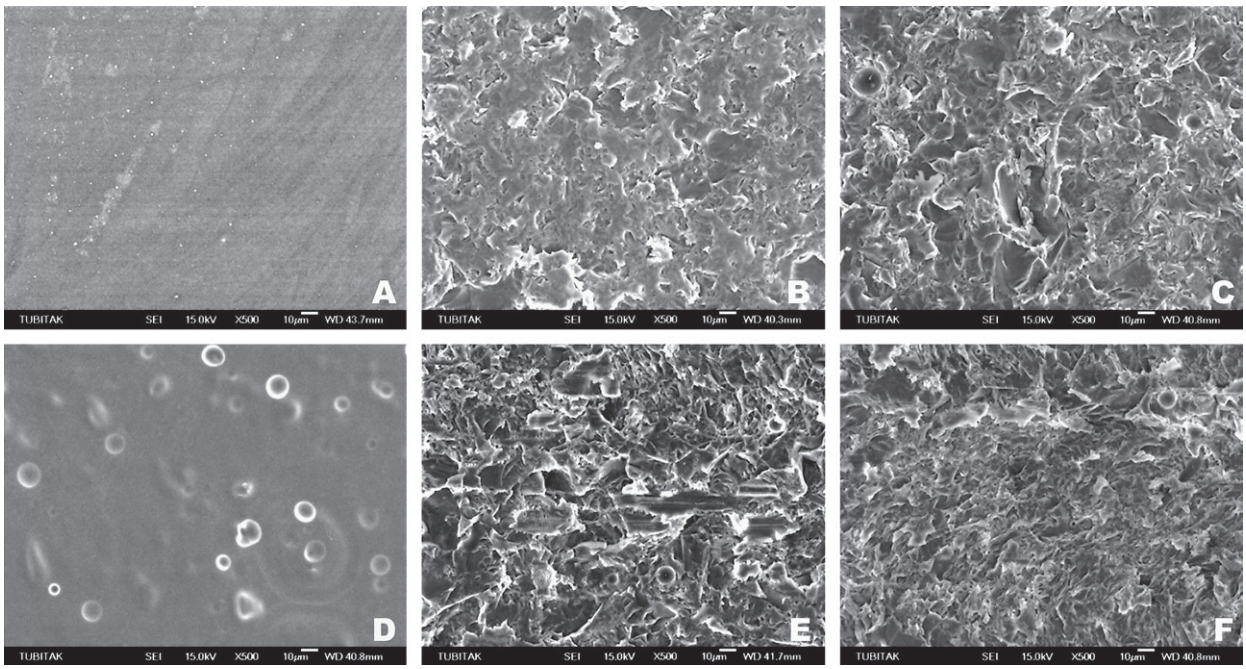

Figure 1 Scanning electron photomicrographs of feldspathic ceramic: (A) intact ceramic, (B) air particle abrasion (APA) with 25 μm Al_2O_3, (C) APA with 50 μm Al_2O_3, (D) chemical etching with 9.6 per cent hydrofluoric acid, (E) roughening with extra-fine (40 μm) diamond burs, and (F) roughening with fine (63 μm) diamond burs. Original magnification, ×500.

1991; Whitlock *et al.*, 1994; Cochran *et al.*, 1997; Chung *et al.*, 1999; Huang and Kao, 2001; Kocadereli *et al.*, 2001; Schmage *et al.*, 2003). Silane presents a chemical link between the dental ceramic and the composite resin, and the organic portion of the molecule enhances the wettability of the ceramic surface, thereby displaying a closer micromechanical bond (Lu *et al.*, 1992).

Chemical roughening with 9.6 per cent HFA showed the lowest SBS for both ceramic groups. However, HFA has been found to be effective for improving bond strengths in other studies (Huang and Kao, 2001; Harari *et al.*, 2003). HFA is applied to increase micromechanical retention creating surface pits by preferential dissolution of the glass phase from the ceramic matrix and to acidify the porcelain surface before silane application (al Edris *et al.*, 1990; Major *et al.*, 1995). The high aluminium oxide containing glaze and the increasing strength of porcelain makes it more resistant to chemical attack and reduces the effect of HFA etching (Zachrisson *et al.*, 1996).

No significant differences were found in this study for SBS between the two APA groups. The SBS achieved with APA was higher than that produced by HFA. However, there was no statistically significant difference between chemical etching with HFA in the lithium disilicate ceramic or APA with 50 μm Al_2O_3 in the feldspathic ceramic. There is disagreement concerning the effectiveness of APA with Al_2O_3 particles in the literature: APA with Al_2O_3 particles was found to be more effective than chemical etching with HFA (Schmage *et al.*, 2003). However, in some studies no significant difference between APA and chemical etching was observed (Gillis and Redlich, 1998). Harari *et al.* (2003) found that application of HFA was more effective than microetching with Al_2O_3 particles.

Roughening with diamond burs showed significantly higher SBS than chemical etching and APA. However, there was no difference between fine and extra-fine diamond burs. Barbosa *et al.* (1995) stated that roughening with coarse diamond burs resulted in higher SBS when compared with other groups, i.e. glazed and deglazed surfaces with sandpaper disks. However, the differences were not observed among the groups, i.e. roughening with a diamond bur, chemical etching with HFA, and APA with Al_2O_3 particles (Sant'Anna *et al.*, 2002). In another study, roughening with diamond burs without silane application showed lower bond strength than chemical etching with HFA with silane and APA with Al_2O_3 particles with silane (Schmage *et al.*, 2003).

With all surface-conditioning methods, lithium disilicate ceramic, in general, showed a higher SBS than feldspathic ceramic. The processing methods and the molecular structures of the two all-ceramic systems resulted in the differences. Lithium disilicate ceramic is processed by heat-press techniques and has more homogeneous and larger molecules (Oh *et al.*, 2000). This structural difference could explain the variations between the bond strengths of the two ceramic systems.

The SEM photomicrographs of the two ceramics etched with 9.6 per cent HFA revealed different surface morphologies. Feldspathic ceramic displayed fewer pits and more unchanged glazed surfaces than the lithium

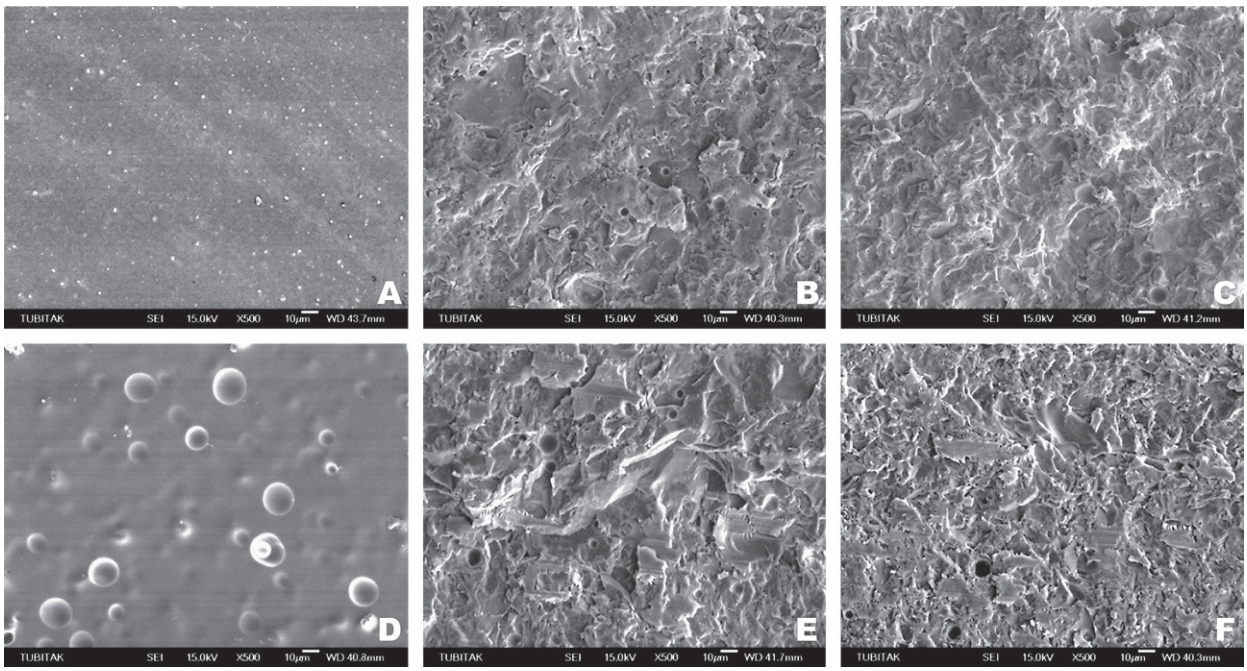

Figure 2 Scanning electron photomicrographs of lithium disilicate ceramic: (A) intact ceramic, (B) air particle abrasion (APA) with 25 µm Al_2O_3, (C) APA with 50 µm Al_2O_3, (D) Chemical etching with 9.6 per cent hydrofluoric acid, (E) roughening with extra-fine (40 µm) diamond burs, and (F) roughening with fine (63 µm) diamond burs. Original magnification, ×500.

disilicate ceramic. For the two ceramics abraded with Al_2O_3, loss of the glazed surface and mild roughening were seen. Uniform peeling or an erosive appearance with shallow penetration and undercuts was observed when compared with chemical etching. The two ceramics roughened with diamond burs showed similar surface morphology: uniform peeling or an erosive appearance with deeper grooves, and additional undercuts were observed when compared with chemical etching and APA.

These different microscopic appearances corroborate the SBS values. The bond strength gradually increased due to the gradual increase in roughening of the ceramic surface. Although roughening of the ceramic surface results in a higher bond strength, removal of the glaze by grinding diminishes the transverse strength of the porcelain to half of that when the glaze is present (Anusavice, 1996). Cracks created during roughening lead to porcelain damage during debonding (Peterson *et al.*, 1998).

For all samples, adhesive failures between the ceramic 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 was stronger than the bond strength between the composite and ceramic. Adhesive failures at the ceramic/composite interface are preferred to avoid ceramic fractures during debonding (Smith *et al.*, 1988). It has been reported that if bond strengths between the ceramic and the composite resin are higher than 13 MPa, cohesive failures are observed in the ceramic (Thurmond *et al.*, 1994). In the present study most of the groups had values higher than 13 MPa which resulted in adhesive failures. Ceramic fractures or cracks were not observed. These findings agree with the results of Harari *et al.* (2003), who observed adhesive failure for HFA and APA groups. This observation is clinically important: no macroscopic damage to the ceramic surface is an indication of long-term integrity of the restoration (Harari *et al.*, 2003).

Conclusion

1. SBS values were found above the optimal range (6–8 MPa), except for feldspathic ceramic treated with HFA and silane.
2. With all surface-conditioning methods, lithium disilicate ceramic, in general, showed a higher SBS than feldspathic ceramic.
3. Although the SBS for feldspathic ceramic was below the optimal range, the SBS for lithium disilicate ceramic was above this range for HFA. For lithium disilicate ceramics HFA might be used for adequate bond strength. Thus, possible surface damage which may be observed after mechanical roughening may be prevented.
4. With feldspathic porcelain, 25 µm Al_2O_3 particles resulted in minimal damage to the porcelain surface, and could be used as it provided sufficient bond strength.
5. For all samples, adhesive failures between the ceramic and the composite resin were seen. No ceramic fractures or cracks were observed.

6. The results of this study cannot solely be associated with the surface-conditioning methods; other factors influencing cohesive fractures of ceramics, such as bonding agent, ceramic type, bracket type, and debonding technique, should be taken into consideration.

Address for correspondence

Tamer Türk
Department of Orthodontics
Faculty of Dentistry
University of Ondokuz Mayıs
55139 Kurupelit-Samsun
Turkey
E-mail: turkset@superonline.com

References

Albakry M, Guazzato M, Swain M V 2004 Effect of sandblasting, grinding, polishing and glazing on the flexural strength of two pressable all-ceramic dental materials. Journal of Dentistry 32: 91–99

al Edris A, al Jabr A, Cooley R L, Barghi N 1990 SEM evaluation of etch patterns by three etchants on three porcelains. Journal of Prosthetic Dentistry 64: 734–739

Anusavice K J 1996 Phillips' science of dental materials. W B Saunders, Philadelphia

Årtun J, Bergland S 1984 Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. American Journal of Orthodontics 85: 333–340

Barbosa V L T, Almeida M A, Chevitarese O, Keith O 1995 Direct bonding to porcelain. American Journal of Orthodontics and Dentofacial Orthopedics 107: 159–164

Bourke B M, Rock W P 1999 Factors affecting the shear bond strength of orthodontic brackets to porcelain. British Journal of Orthodontics 26: 285–290

Chung C H, Brendlinger E J, Brendlinger D L, Bernal V, Mante F K 1999 Shear bond strengths of two resin-modified glass ionomer cements to porcelain. American Journal of Orthodontics and Dentofacial Orthopedics 115: 533–535

Cochran D, O'Keefe K L, Turner D T, Powers J M 1997 Bond strength of orthodontic composite cement to treated porcelain. American Journal of Orthodontics and Dentofacial Orthopedics 111: 297–300

Eustaquio R, Garner L D, Moore B K 1988 Comparative tensile strengths of brackets bonded to porcelain with orthodontic adhesive and porcelain repair systems. American Journal of Orthodontics and Dentofacial Orthopedics 94: 421–425

Gillis I, Redlich M 1998 The effect of different porcelain conditioning techniques on shear bond strength of stainless steel brackets. American Journal of Orthodontics and Dentofacial Orthopedics 114: 387–392

Guazzato M, Albakry M, Swain M V, Ironside J 2002 Mechanical properties of In-Ceram alumina and In-Ceram zirconia. International Journal of Prosthodontics 15: 339–349

Harari D, Shapira-Davis S, Gillis I, Roman I, Redlich M 2003 Tensile bond strength of ceramic brackets bonded to porcelain facets. American Journal of Orthodontics and Dentofacial Orthopedics 123: 551–554

Huang T H, Kao C T 2001 The shear bond strength of composite brackets on porcelain teeth. European Journal of Orthodontics 23: 433–439

Kao E C, Boltz K C, Johnston W M 1988 Direct bonding of orthodontic brackets to porcelain veneer laminates. American Journal of Orthodontics and Dentofacial Orthopedics 94: 458–468

Kao E C, Johnston W M 1991 Fracture incidence on debonding of orthodontic brackets from porcelain veneer laminates. Journal of Prosthetic Dentistry 66: 631–637

Kern M, Thompson V P 1994 Sandblasting and silica coating of a glass-infiltrated alumina ceramic: volume loss, morphology, and changes in the surface composition. Journal of Prosthetic Dentistry 71: 453–461

Kocadereli I, Canay S, Akca K 2001 Tensile bond strength of ceramic orthodontic brackets bonded to porcelain surfaces. American Journal of Orthodontics and Dentofacial Orthopedics 119: 617–620

Lu R, Harcourt J K, Tyas M J, Alexander B 1992 An investigation of the composite resin/porcelain interface. Australian Dental Journal 37: 12–19

Major P W, Koehler J R, Manning K E 1995 24-hour shear bond strength of metal orthodontic brackets bonded to porcelain using various adhesion promoters. American Journal of Orthodontics and Dentofacial Orthopedics 108: 322–329

Nebbe B, Stein E 1996 Orthodontic brackets bonded to glazed and deglazed porcelain surfaces. American Journal of Orthodontics and Dentofacial Orthopedics 109: 431–436

Newman S M, Dressler K B, Grenadier M R 1984 Direct bonding of orthodontic brackets to esthetic restorative materials using a silane. American Journal of Orthodontics 86: 503–506

Oh S C, Dong J K, Luthy H, Scharer P 2000 Strength and microstructure of IPS Empress 2 glass-ceramic after different treatments. International Journal of Prosthodontics 13: 468–472

Özcan M, Vallittu P K, Peltomäki T, Huysmans M, Kalk W 2004 Bonding polycarbonate brackets to ceramic: effects of substrate treatment on bond strength. American Journal of Orthodontics and Dentofacial Orthopedics 126: 220–227

Pannes D D, Bailey D K, Thompson J Y, Pietz D M 2003 Orthodontic bonding to porcelain: a comparison of bonding systems. Journal of Prosthetic Dentistry 89: 66–69

Peterson I M, Pajares A, Lawn B R, Thompson V P, Rekow E D 1998 Mechanical characterization of dental ceramics by Hertzian contacts. Journal of Dental Research 77: 589–602

Reynolds I R 1975 A review of direct orthodontic bonding. British Journal of Orthodontics 2: 171–178

Sant'Anna E F, Monnerat M E, Chevitarese O, Stuani M B 2002 Bonding brackets to porcelain—*in vitro* study. Brazilian Dental Journal 13: 191–196

Schmage P, Nergiz I, Herrman W, Özcan M 2003 Influence of various surface-conditioning methods on the bond strength of metal brackets to ceramic surfaces. American Journal of Orthodontics and Dentofacial Orthopedics 123: 540–546

Smith G A, McInnes-Ledoux P, Ledoux W R, Weinberg R 1988 Orthodontic bonding to porcelain-bond strength and refinishing. American Journal of Orthodontics and Dentofacial Orthopedics 94: 245–252

Thurmond J W, Barkmeier W W, Wilwerding T M 1994 Effect of porcelain surface treatments on bond strengths of composite resin bonded to porcelain. Journal of Prosthetic Dentistry 72: 355–359

Wen M Y, Mueller H J, Wozniak W T 1999 Comparative mechanical property characterization of 3 all-ceramic core materials. International Journal of Prosthodontics 12: 534–541

Whitlock 3rd O B, Eick J D, Ackerman Jr J R Glaros A G, Chappell R P 1994 Shear strength of ceramic brackets bonded to porcelain. American Journal of Orthodontics and Dentofacial Orthopedics 106: 358–364

Winchester L 1991 Direct orthodontic bonding to porcelain: an *in vitro* study. British Journal of Orthodontics 18: 299–308

Wood D P, Jordan R E, Way D C, Galil K A 1986 Bonding to porcelain and gold. American Journal of Orthodontics 89: 194–205

Zachrisson B U, Büyükyılmaz T 1993 Recent advances in bonding to gold, amalgam, and porcelain. Journal of Clinical Orthodontics 27: 661–675

Zachrisson Y Ø, Zachrisson B U, Büyükyılmaz T 1996 Surface preparation for orthodontic bonding to porcelain. American Journal of Orthodontics and Dentofacial Orthopedics 109: 420–430

Zelos L, Bevis R R, Keenan K M 1994 Evaluation of the ceramic/ceramic interface. American Journal of Orthodontics and Dentofacial Orthopedics 106: 10–21