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Original Article

The effect of various mechanical and chemical surface conditioning on the bonding of orthodontic brackets to all ceramic materials

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Abstract *Background/purpose:* Increasing the bond strength between the orthodontic brackets and all-ceramic materials is one of the challenges facing orthodontists. The purpose of this study is to assess the shear bond strength (SBS) of metal brackets to two types of all ceramic materials using various surface mechanical and chemical conditioning methods.
Materials and methods: Sixty ceramic blocks were prepared using two types of all ceramic materials (IPS e.max and VITA Suprinity® PC) and treated with 3 surface treatments; surface etching with 9.6% hydrofluoric acid (HFA) for 2 mins; surface roughening with Sof-Lex finishing discs; and surface roughening with Sof-Lex finishing discs and etching with HFA. Metal brackets were attached to the surface of the ceramic blocks using light cure orthodontic adhesive. Samples were subjected to 2000 thermo-cycles (5–50 °C) and the SBS was assessed using Instron machine. The adhesive remnant index (ARI) was evaluated under light microscope. Descriptive and group comparison were calculated using Two-way ANOVA, Post-hoc Tukey's and Chi-square tests and significance level set at ($P < 0.05$).
Results: surface roughening of both ceramic materials with Sof-Lex discs and HFA resulted in a significant increase in SBS compared to other experimental groups ($P < 0.05$). However, VITA Suprinity ceramic prepared with Sof-Lex discs only showed the lowest SBS. The distribution of the ARI scores was significantly different between the groups ($P < 0.05$).
Conclusion: Surface preparation of all ceramic materials with Sof-Lex discs and hydrofluoric

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acid combination produces the highest SBS to metallic orthodontic brackets.

Introduction

The current increased demand on restorations used for esthetic purposes resulted in an increased use of all-ceramic restorations.[1] The development of computer-aided design technologies (CAD/CAM) of zirconia blocks further increased the clinical usage of all ceramic crowns.[2,3] Concomitantly, the demands on adult orthodontics is also increasing nowadays. The bonding of orthodontic brackets directly to the surfaces of ceramic material have shown a high degree failure rate when compared to enamel surface bonding.[4] Therefore, increasing the bond strength between the orthodontic brackets and various types of all-ceramic materials is one of the challenges that orthodontist has to deal with.

Many studies assessed the orthodontic bonding materials which are: etching, primer, and bonding material. The use of self-adhesive resin composite cement along with ceramic primer has shown a positive effect on the SBS when bonding brackets to zirconia.[5] Bracket type, material and mode of retention also affected the strength of bond to ceramic restorations.[4] Guida et al., however, reported that the mode of bond failure was affected mostly by the treatment of the glass-ceramic surface and not by the bracket type.[6]

Other attempts suggested to modify the characteristics of the ceramic surfaces to withstand orthodontic brackets with sufficient bond strength.[1] Three main approaches according to their mechanism of action were suggested: chemical, mechanical, or chemico-mechanical surface treatment.[7] The mechanical surface conditioning techniques included acid etching, surface roughening with a sandpaper discs or diamond drill and sandblasting with aluminum oxide particles.[5,8–12] The acid etching treatment of the porcelain surface with hydrofluoric acid (HFA) has been proved to increase the strength of the bond and the glass phase of ceramics attacked by hydrofluoric acid, creating multiple micro porosities leading to micro-mechanical bonding with resin composite.[5,13] García-Sanz et al. and Xu et al. assessed the effect of laser etching as a ceramic surface treatment and reported positive results on the SBS of orthodontic brackets.[9,12] On the other hand, Buyuk & Kucukekenci reported that the SBS was significantly changed mainly by the ceramic type and the procedure of bonding and not by the etching procedure.[11] Amer & Rayyan found that sandblasting surface treatment achieved the highest SBS. They also reported that the use of Sof-Lex disc for surface roughening is a successful surface treatment for glazed zirconia, while bonding to untreated glazed zirconia in most cases resulted in bond failure.[10]

The chemical surface-conditioning techniques included, chemical preparation with universal or ceramic primers or silanes use (gamma-methacryloxypropyltrimethoxy silane).[11,14–18] Most studies recommended the use of either universal primer or ceramic primers combined with orthodontic primer better than using ceramic primers alone.[11,16,18]

The method used for chemo-mechanical treatment of ceramic surfaces is tribochemical silica – coating.[11,19,20] Such method did not show positive effect on the shear strength of orthodontic brackets when compared to sandblasting alone[20] or sandblasting and universal primer.[19]

Despite the many studies that have tested different ceramic surface treatments, there is still a lack of bonding protocol that provide minimal roughening of the restoration surface to avoid ceramic surface micro-cracks, as well resulting in favourable SBS between orthodontic bracket and the restoration to withstand orthodontic forces during treatment.[11,14,21]

Therefore, the aim of the present study was to assess the SBS of metal brackets bonded to two types of all ceramic surfaces using various mechanical and chemical surface treatment methods.

Materials and methods

Ethical approval for this laboratory study was taken from the Research Ethical Committee of King Abdulaziz University, Faculty of Dentistry (Ethical approval No: 089-10-17).

Sample preparation

Sixty square shaped ceramics (10 mm × 10 mm × 2 mm) were crystallized and glazed according to manufacturer instructions, using two types of all ceramic materials ($n = 30$). The first material was the IPS e.max (Ivoclar-Vivaden AG, Schaan, Liechtenstein) which is a type of lithium disilicate core ceramic. The second material was the VITA Suprinity® PC (Vita Zahnfabick, Bad Säckingen, Germany) which is a type of lithium silicate reinforced with 10%W zirconia blanks.

All ceramic blocks were mounted on light cure acrylic resin (Meditray, Promedica Dental Material GmbH, Germany).

The ceramic blocks from each ceramic material were divided randomly into three groups ($n = 10$ each group); Groups I, II & III were constructed from VITA Suprinity® PC (Vita Zahnfabick), while Groups IV, V & VI were constructed from IPS e. max (Ivoclar-Vivaden AG).

Ceramic samples were then subjected to 3 different surface preparation techniques according to the following group distributions:

GI & GIV: Etching for 2 min with 9.6% hydrofluoric acid (HFA), then rinsing with water for 30 s and air drying.

GII & GV: Mechanical roughening with Soflex discs (3 M ESPE) (Coarse discs) under water coolant.

GII &VI: Mechanical roughening with Soflex discs (Coarse discs) under water coolant, etching for 2 min with 9.6% hydrofluoric acid, rinsing with water for 30 s and air drying.

After surface preparation of ceramic samples, the prepared ceramic surface was covered by silane (Prosil, Dentscare, Joinville, Brasil) using a specialized micro-brush and dried for 60 s according to manufacture instructions.

Orthodontic metal brackets for maxillary right central incisors (Victory-series brackets, 3 M Unitek, Monrovia, CA, USA), were chosen. The adhesive system, Transbond XT Light Cure Orthodontic Adhesive (3 M Unitek, Monrovia, CA, USA), used in this study. It consists of a primer and adhesive. The primer was applied in a thin uniform layer with a microbrush on the prepared ceramic surface. The light cure adhesive was applied to bracket mesh. The brackets were then bonded to the ceramic surface and a force of 150 g was applied to produce a consistent adhesive surface and the excess adhesive was removed from around the bracket. The adhesive was light-cured for 20s mesial and distal to brackets, using a light-emitting diode device (Mini LED) (Satelec@Acteon Inc., Merignac cedex, France). The test samples were stored in distilled water for 24 h. Prior to testing, all blocks were thermo-cycled (2000 times between 5° and 55°C) with 30 s dwelling time, in order to simulate the oral environment.

The bracket base was measured by a digital caliper and the surface area was calculated and found to be ($2.8\,mm \times 3.6\,mm = 10.1\,mm^2$).

Shear bond strength (SBS) assessment

Each sample was loaded into the Instron Universal Testing Machine (Instron model 5944, Canton, MA, USA). The samples were oriented so that its long axis becomes perpendicular to the applied force. A shear force was delivered with 0.5 mm/min crosshead speed applied at the bracket base-enamel interface until fracture occurred. The load of failure (N) was recorded and converted into megapascals by dividing (N) by the surface area of the base of the orthodontic bracket, which was ($10\,mm^2$).

Adhesive remnant assessment

After de-bonding, all brackets and ceramic blocks in the examined groups were examined under a stereomicroscope under ($\times 10$) magnifications and the adhesive remnants were recorded using the modified Adhesive Remnant Index (ARI)[22] as follows:

0 All the adhesive was removed with the bracket
1 The adhesive remnant is covering less than 50% of the bracket site on the ceramic surface.
2 The adhesive remnant is covering more than 50% of the bracket site on the ceramic surface.
3 All the adhesive was left on the bracket site of the ceramic surface.

Statistical analysis

Descriptive statistics for the SBS (mean and standard deviations) were recorded. Group comparison were calculated using Two-way ANOVA and Post-Hoc Tukey test with the ceramic type and the surface conditioning method as the random factors. The ARI scores for the different groups were compared using Chi-Square test. Data collection and analysis was done using SPSS (Version20.0, IBM, and New York, USA). The significance level was set at ($P < 0.05$).

Results

Table 1 shows the means, standard deviations and significant differences between the different experimental groups.

Surface preparation of ceramic material showed a significant influence on SBS ($P < 0.001$). Interaction between

Table 1 Mean and standard deviations in MPa for the shear bond strength (SBS) among the study groups.

Surface preparation methods	Ceramic type						P-value within surface preparations
	VITA Suprinity® PC (n = 30)			IPS e. max (n = 30)			
	Group (N)	N (%) of Samples de-bonded after aging	Mean SBS in MPa (SD)	Group (N)	N (%) of Samples de-bonded after aging	Mean SBS in MPa (SD)	
HFA	GI (10)	1 (10%)	8 $^{b\ c}$ (4.5)	GIV (10)	3 (30%)	5.4 ^{c} (1.4)	0.000***
Soflex discs	GII (10)	5 (50%)	5.6 ^{c} (2)	GV (10)	2 (20%)	12 $^{a\ b}$ (4)	
Soflex discs & HFA	GIII (10)	0 (0%)	16 ^{a} (5)	GVI (10)	0 (0%)	14 $^{a\ b}$ (3.3)	
P-value between ceramic types	0.04*						

N: number, SD: standard deviation, SBS: shear bond strength, MPa: mega-pascal.
*,***: denotes statistical significance (critical region: $P < 0.05$, $P < 0.001$).
^{a,b,c}: denotes Post-hoc Tukey's statistical differences between the groups (critical region: $P < 0.05$).

ceramic material and surface preparation also showed a significant influence on SBS ($P < 0.05$).

VITA Suprinity (Vita Zahnfabick) ceramic surfaces treated with Soflex discs and HFA combination (GIII) provided the highest SBS to metal orthodontic brackets (16 $\pm$ 5 MPa). On the other hand, VITA Suprinity treated with Soflex discs only or HFA only (GII, GI) and IPS e. max treated with HFA only (GIV) resulted in the lowest SBS values (5.6 $\pm$ 2, 8 $\pm$ 4.5, 5.4 $\pm$ 1.4 MPa, respectively). Also, there was no significant difference in the SBS between GIII (VITA Suprinity treated with HFA and Soflex discs) and the IPS e max (Ivoclar-Vivaden AG) treated either by Soflex discs and HFA combination (14 $\pm$ 3.3 MPa) or treated with Soflex discs only (12 $\pm$ 4 MPa) ($P > 0.05$). The number of samples de-bonded after thermocycling and before shear bond strength test was highest in GII (VITA Suprinity® PC + Soflex discs) (n = 5, 50%) followed by GIV (IPS e. max + HFA) (n = 3, 30%).

Table 2 shows the results of ARI scores. None of the groups had samples with ARI score 3. On the other hand, Groups I, II & IV had almost all the samples with ARI score 0, which indicates that the mode of failure occurred at the ceramic—adhesive interface. A significant difference in ARI score distribution among the groups was also reported ($P < 0.05$).

Discussion

Bonding orthodontic brackets to ceramic surfaces has been assessed extensively in the literature. Different etching types and times, primer procedures, as well as ceramic material were assessed but with controversial findings. The present study investigated the SBS of metal brackets bonded to two new types of all ceramic materials using different mechanical and chemical surface conditioning methods. The two all ceramic materials used were; IPS e. max (Ivoclar-Vivaden AG) which is a lithium disilicate-based core ceramic, and VITA Suprinity (Vita Zahnfabick) which is a lithium silicate reinforced with zirconia blanks. Results indicated that the VITA Suprinity (Vita Zahnfabick) treated with Soflex discs only or HFA only as well as the IPS e. max (Ivoclar-Vivaden AG) treated with HFA only resulted in the lowest shear bond strength values. However, the VITA Suprinity (Vita Zahnfabick) treated with HFA only might be considered as having a clinically acceptable results as its shear bond strength was within the range of the clinically acceptable shear bond strength that can withstand orthodontic forces recommended by Reynolds, which should not be less than 5.8—7.8 MPa.[23] On the other hand, the VITA Suprinity (Vita Zahnfabick) treated with HFA and Soflex discs as well as the IPS e. max (Ivoclar-Vivaden AG) treated with HFA and Soflex discs or Soflex discs only showed high shear bond strength values.

Hydrofluoric acid etching of different ceramic materials is performed to remove the glassy matrix of ceramics and expose lithium disilicate and Zirconia crystals.[24]

In the present study, using both surface preparation methods (acid etching with HFA and mechanical roughening with Soflex discs) were more efficient in creating micromechanical retention. However, the mechanical roughening using Soflex discs only was more efficient with lithium disilicate based ceramics (IPS e. max) compared to roughening with hydrofluoric acid, which may be explained by the ability of Soflex discs coarse particles to create rougher surface. This was different with the Zirconia reinforced ceramics, as Soflex discs were less efficient in roughening the surface when compared to hydrofluoric acid. Also, using Soflex discs only showed 50% failure rate after aging. This indicate the harder surface of the zirconia reinforce ceramics making the mechanical roughening more difficult and the chemical removal of the glassy matrix and crystal exposure by using the hydrofluoric acid more effective in creating a rough surface and improving bond strength with a lower failure rate of 10%. Therefore, applying both techniques in zirconia reinforced ceramic and lithium disilicate ceramics was having a synergistic effect in improving bond strength and durability as all samples treated by both techniques showed 0% de-bonding after aging.

Borges et al., and Kim et al. reported that hydrofluoric acid etching is the most appropriate treatment for lithium disilicate ceramics.[8,20] In contrary, results of the current study, however, showed that HFA treatment alone resulted in low shear bond strength with IPS e.max (Ivoclar-Vivaden AG) as well as a low but acceptable SBS with VITA Suprinity (Vita Zahnfabick) material. Similarly, Mehmeti et al. reported that surface etching of zirconia and lithium-disilicate with HFA compared to etching with phosphoric acid followed by silane application did not increase the SBS significantly.[25] On the other hand, treatment with HFA and Soflex discs showed in the current study the highest SBS for both IPS e. max (Ivoclar-Vivaden AG) and VITA Suprinity (Vita Zahnfabick) material.

As stated earlier, the best bonding protocol should result in a strong SBS that can withstand orthodontic loads, but not to the extent that will produce damage to the ceramic restoration surface during the de-bonding procedure.[7,14,21] Thus, the best surface treatment is expected to result in minimal adhesive remnant on the ceramic surface at debonding to avoid further damaging to the restoration during adhesive removal. For the current study design, it can be stated that debonding results with ARI scores 0 or 1 might be the best preferable result. Accordingly, results showed that the best surface treatment for VITA Suprinity (Vita Zahnfabick) is when treated with Soflex only or HFA only, and the best surface treatment for IPS e. max (Ivoclar-Vivaden AG) is when treated with HFA only. However, the combination of the two techniques resulted in acceptable

Table 2 The ARI scores (number and percentages) among the study groups.

Groups	N	ARI Scores				P-value
		0	1	2	3	
G I	10	10 (100%)	0 (0%)	0 (0%)	0 (0%)	0.019*
G II	10	10 (100%)	0 (0%)	0 (0%)	0 (0%)	
G III	10	5 (50%)	3 (30%)	2 (20%)	0 (0%)	
G IV	10	9 (90%)	1 (10%)	0 (0%)	0 (0%)	
G V	10	7 (70%)	1 (10%)	2 (20%)	0 (0%)	
G VI	10	6 (60%)	4 (40%)	0 (0%)	0 (0%)	

N: number, ARI: adhesive remnant index.
*: denotes statistical significance (critical region: $P < 0.05$).

values for both the shear bond strength and the ARI score distribution.

The findings of the current study showed that VITA Suprinity (Vita Zahnfabick) treated with Soflex discs only or HFA only as well as the IPS e. max (Ivoclar-Vivaden AG) treated with HFA only resulted in the lowest SBS. VITA Suprinity (Vita Zahnfabick) treated with HFA only resulted in a low but clinically acceptable SBS. Furthermore, the combination of HFA and Soflex discs surface treatment showed the highest SBS for the two ceramic materials assessed; IPS e.max (Ivoclar-Vivaden AG) and VITA Suprinity (Vita Zahnfabick). The ARI score was (0) for all the samples of VITA Suprinity (Vita Zahnfabick) treated with HFA only or Soflex discs only and IPS e.max (Ivoclar-Vivaden AG) treated with HFA only. This indicates that the failure mode occurred at the ceramic—adhesive interface.

Declaration of Competing Interest

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