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Original Article

Can a Self-etching Primer be Effective in Bonding Aligner Attachments to Different Types of Ceramics?

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Main Points

- Self-etch ceramic primer increases the bond strength of aligner attachments to lithium disilicate ceramics.
- Self-etch primer did not improve the bond strength of the aligner attachments for monolithic zirconia ceramics.
- The resin attachment remnant index can be used to determine the remnant amount of aligner attachment.

ABSTRACT

Objective: This *in vitro* study aimed to evaluate the effectiveness of pretreatment with a self-etching primer for bonding aligner attachments to lithium disilicate (LD) and monolithic zirconia (MZ) ceramics.

Methods: Forty ceramics, including LD (n=20) and MZ (n=20), were divided into four study groups according to the surface pretreatments: LD specimens pretreated with universal primer (Monobond Plus, MP) after hydrofluoric acid etching (Group 1); MZ ceramics pretreated with MP after sandblasting (Group 2); LD ceramics pretreated with self-etching ceramic primer (Monobond etch & prime, MEP) (Group 3); and MZ ceramics pretreated with MEP after sandblasting (Group 4). The aligner composite (GC Aligner Connect) and universal adhesive (GPremio Bond) were used to prepare the resin attachments. The bond strength was evaluated by micro-shear bond strength (SBS) testing (0.1 mm/min) after thermocycling, and the remnant adhesive was scored according to the resin attachment remnant index (RARI). The SBS data were analyzed using ANOVA and Tukey tests, and the RARI scores were analyzed using the chi-square test.

Results: Group 1 had the lowest SBS, and group 2 had the highest SBS. There were significant differences between the groups in terms of bond strength ($p<0.05$). The RARI scores showed no significant differences, regardless of the pretreatment and ceramic type.

Conclusion: The use of a self-etching primer increased the bond strength of resin attachments on LD ceramics. For zirconia ceramics, both ceramic primers are recommended for aligner attachment bonding.

Keywords: Aligner attachment, ceramic, self-etching primer, shear bond strength

INTRODUCTION

Clear aligner (CA) treatment has gained popularity due to increased esthetic concerns. Adult patients undergoing CA therapy have the highest quality-of-life scores compared with labial and lingual treatments.[1] Other advantages of CA therapy include shorter treatment duration and chair time in mild to moderate cases over traditional fixed orthodontic treatment.[2] Most available aligner systems require resin attachments to retain appliances and better three-dimensional (3D) control of tooth movements.[3] Therefore, the adhesion between

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the resin attachment and surfaces must be strong to withstand orthodontic and chewing forces under intraoral conditions.

Due to advancements in adhesive materials, it has become easier to provide adequate attachment bond strength on natural teeth.[4] However, the adhesion protocol for attaching aligner attachments to glass-based ceramics or zirconia remains uncertain in clinical practice. The primary goal of ceramic pretreatment is to create surface roughness, followed by primer application to facilitate the bonding process. The protocols vary depending on the chemical nature of the ceramics. For lithium disilicate (LD) glass-ceramics, the most common method involves hydrofluoric acid (HFA) etching followed by silanization.[5] On the other hand, sandblasting is commonly used for bonding orthodontic brackets to Y-TZP zirconia ceramics.[6] When the ceramic surfaces are pretreated, either mechanically by sandblasting or chemically by etching, a ceramic primer is used as a silane coupling agent.[5] Therefore, clinicians need to determine the appropriate pretreatment method for applying aligner attachments to different ceramic surfaces due to their dissimilar structures in the bracket-bonding procedure.

The self-etching ceramic primer (Monobond etch & prime) has been introduced as a single-component primer, especially for glass-based ceramics, and an alternative to pretreatment with HFA etching due to its adverse effects on systemic toxicity, eye injuries, inhalation, and ingestion-related symptoms.[7] In recent studies, this self-etching primer has demonstrated adequate bracket bonding strength with no damage on ceramic surfaces in the case of debonding.[8,9] This raises the question of whether the self-etching primer can serve as an alternative to conventional pretreatment when bonding aligner attachments to different ceramic surfaces. The aim of this study was to evaluate the effectiveness of pretreatment with a self-etching primer for bonding of aligner attachments to LD and monolithic zirconia (MZ) ceramics. Therefore, the null hypothesis was that there would be no difference in bond strength and remnant amount of aligner attachments between pretreatment with self-etching or universal ceramic primer, regardless of the ceramic type.

METHODS

Sample size calculations were performed using software based on a previous study.[10] The required sample size in each group was estimated to be 10, with an alpha-type error of 0.05, power of 0.80, and effect size of 0.577.

Specimen Preparation

Forty disk-shaped specimens (5 mm in diameter and 2 mm thick), including LD (n=20) and MZ (n=20), were fabricated using the milling method. LD specimens were then subjected to crystallization in a ceramic oven (Programat P300, Ivoclar Vivadent, Schaan, Liechtenstein) according to the manufacturer's guidelines (840 °C, 20-25 min). The MZ specimens were sintered in a furnace (inLab Profire, Dentsply Sirona, Germany) according to the manufacturer's instructions (1500 °C, 135 min). After glazing the ceramic surfaces, the specimens were individually embedded in self-cured acrylic resin, leaving the ceramic surfaces exposed. Four study groups (n=10) were created according to the surface pretreatment as follows:

• Group 1: LD pretreated with universal ceramic primer after HFA etching.

• Group 2: MZ pretreated with universal ceramic primer after sandblasting.

• Group 3: LD pretreated with self-etching ceramic primer.

• Group 4: MZ pretreated with self-etching ceramic primer after sandblasting.

Surface Treatments

The materials used and their compositions are shown in Table 1. The ceramic material was etched with 5% HFA (Condac porcelana, FGM, Joinville, Brasil) for 20 s, rinsed for 30 s, and finally air-dried in group 1. Sandblasting was conducted with 50 µm grain size Al_2O_3 particles from a distance of 10 mm for 15 s in groups 2 and 4. In groups 1 and 2, a universal ceramic primer (Monobond Plus, Ivoclar Vivadent, Schaan, Liechtenstein) was applied with a microbrush and allowed to react for 60 s. Subsequently, the excess was dispersed with a strong air stream to ensure solvent evaporation. In groups 3 and 4, a self-etching ceramic primer (Monobond etch & prime-MEP, Ivoclar Vivadent, Schaan, Liechtenstein) was applied using a microbrush, agitated into the surface for 20 seconds, allowed to react for another 40 seconds, rinsed thoroughly with water for 20 s, and air-dried for 10 s.

Attachment Preparation and Bonding Procedures

One aligner attachment ($3 \times 3 \times 1$ mm^3) was specially designed (Solidworks, Dassault Systemes SolidWorks Corp.,Waltham, MA, USA), and another software (Mimics, Materialise, Leuven, Provincie Vlaams-Brabant, Belgium) was used to prepare 3D models of the ceramic specimens. All attachments were bonded to each specimen using an attachment template produced by thermoforming an aligner material (Duran, Scheu Dental, Iserlohn, Germany).

Universal adhesive (G-Premio Bond, GC, Tokyo, Japan) was applied to the pretreated surface and light-cured for 10 s. Then, a specially developed aligner composite (GC Aligner Connect, GC Corp, Tokyo, Japan) was applied to the attachment wells of each template, pressed onto the ceramic surface, and then light-cured for 10 s. All bonding procedures were performed by the same researcher (S.Ç).

After the bonding procedure, the specimens were kept in distilled water until the thermocycling process. Thermocycling was performed between 5-55 °C with a dwell time of 30 s at 1000 cycles. A micro-shear bond strength (SBS) testing unit (Mod Dental, Ankara, Turkey) was used at a crosshead speed of 0.1 mm/min until detachment to assess the bond strength of the resin attachments (Figure 1). After the SBS test, the remaining attachment was scored under a stereomicroscope

Table 1. The materials used and their respective compositions

Ceramic type	Manufacturer	Composition
Lithium disilicate (IPS e.max CAD)	Ivoclar Vivadent, Schaan, Liechtenstein	SiO_2 57.0-80.0%, Li_2O 11.0-19.0%, K_2O 0.0-13.0%, P_2O_5 0.0-11.0%, ZrO_2 0.0-8.0%, ZnO 0.0-8.0%, Colorants 0.0-18.0%
Monolithic zirconia (Cercon HT)	Dentsply Sirona, Hanau, Germany	Zirconium oxide Yttrium oxide 5% Hafnium oxide <3% Aluminium oxide, Silicon oxide, other oxides <2%
Pretreatment		
Condac Porcelana 5%	FGM Produtos Odont, Joinville, SC, Brazil	5% Hydrofluoric acid
Monobond Plus	IvoclarVivadent, Schaan, Liechteinstein	Ethanol, silane, 10-MDP, and disulfide acrylate
Monobond Etch & Prime	Ivoclar Vivadent, Schaan, Liechteinstein	Silane, ammonium polyfluoride (etchant), alcohol, and water
Attachment bonding		
G-Premio Bond	GC, Tokyo, Japan	MDP, 4-MET, MEPS, methacrylate monomer, acetone, water, initiator, silica filler
GC Aligner Connect	GC Orthodontics, Alsip, IL, USA	Esterification products of 4,4'-isopropylidenediphenol, ethoxylated and 2-methylprop-2-enoic acid, 2,2-dimethyl-1,3-propanediyl bismethacrylate, 1,3,5-Triazine-2,4,6-triamine, polymer with formaldehyde, titanium dioxide, UDMA

(Olympus, SZ61, Munster, Germany) at 20x magnification according to the resin attachment remnant index (RARI). This index was developed on the basis of the original description of Artun and Bergland,[11] although there was no bracket mesh base. The amount of remnant attachment was expressed as a percentage, and the surface damage was also note, resulting in a final score. Consequently, the RARI included five scores as follows:

0: No resin attachment to the surface.

1: Less than 25% of the resin attachment remains on the surface.

2: More than 25% and less than 50% of the resin attachment remains on the surface.

3: More than 50% of the resin attachment is left on the surface.

4: Surface damage.

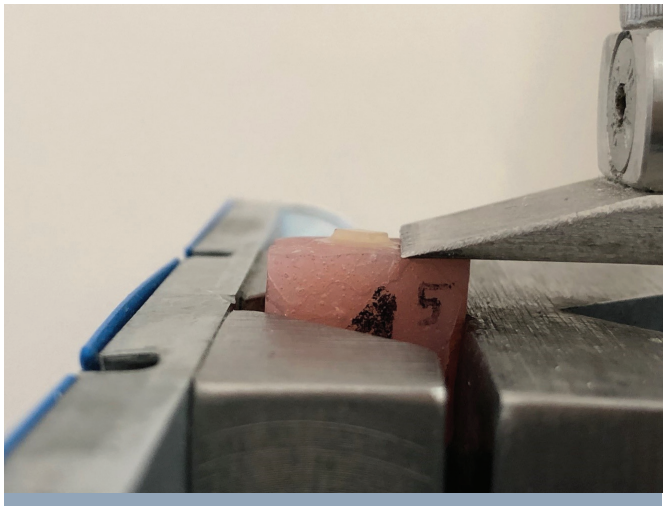

Figure 1. The SBS test
SBS, shear bond strength

Statistical Analysis

The data were analyzed using SPSS software (vers. 21.0, SPSS Inc, Chicago, IL, USA). The normality of distribution was tested using the Shapiro-Wilk test. One-way ANOVA and Tukey tests were used to compare the SBS results. The RARI scores were analyzed using the chi-square test. For all tests, $p<0.05$ was considered statistically significant.

RESULTS

The mean SBS values and intergroup comparisons are shown in Table 2. The pretreatment of LD ceramics with HFA and MP showed the lowest mean SBS value (6.02±2.19) in group 1, whereas the pretreatment of MZ ceramics with MP after sandblasting showed the highest mean SBS value (14.20±6.26) in group 2. There were significant differences between the groups in terms of SBS results ($p=0.002$). The mean SBS value of group 1 was significantly lower than that of the other groups ($p<0.05$). The SBS values are shown as a box plot in Figure 2.

Analysis of the RARI scores provided valuable information concerning remnant attachment on ceramic surfaces. One specimen for each score is shown in Figure 3. There were no significant differences among the groups in terms of RARI scores ($p>0.05$, Table 3). In addition, no ceramic damage was observed during this study.

DISCUSSION

The demand for CA treatment has increased among adults with ceramic restorations recently. Therefore, the appropriate method for conducting ceramic surface treatment in clinical practice has been a topic of discussion. Although many alternatives have been recommended for bracket bonding to LD and MZ ceramics,[12-16] there are limited data on aligner attachment bonding to different ceramics. In a recent study,

Table 2. The comparison of SBS values (MPa) of study groups

Groups	n	Mean±SD	95% confidence interval		Min.-Max.	p value	Post-hoc tests	p value
			Lower Bound	Upper Bound				
Group 1 (LD+HFA+ MP)	10	6.02±2.19[a]	4.46	7.59	1.61-8.62	0.002	LD+HFA+MP versus MZ+S+MP	0.003
Group 2 (MZ+S+MP)	10	14.20±6.26[b]	9.72	18.69	7.02-25.11		LD+HFA+MP versus LD+MEP	0.020
Group 3 (LD+MEP)	10	12.58±5.57[b]	8.59	16.57	4.82-21.49		LD+HFA+MP versus MZ+S+MEP	0.022
Group 4 (MZ+S+MEP)	10	12.48±3.94[b]	9.66	15.29	8.74-20.18		MZ+S+MP versus LD+MEP	0.871
							MZ+S+MP versus MZ+S+MEP	0.849
							MZ+S+MEP versus MZ+S+MEP	0.986

Different letters ([a] and [b]) indicate statistically significant difference between groups (Tukey's test; $p<0.05$).
LD, lithium disilicate; HFA, hydrofluoric acid etching; MP, monobond plus (universal primer); MEP, monobond etch & prime (self-etching primer); MZ, monolithic zirconia; S, sandblasting; SD, standard deviation

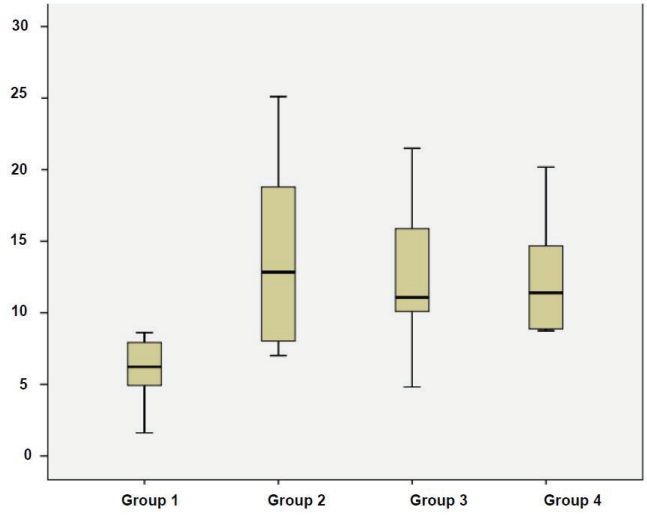

Figure 2. Box plot showing SBS values (MPa) of the study groups
SBS, shear bond strength

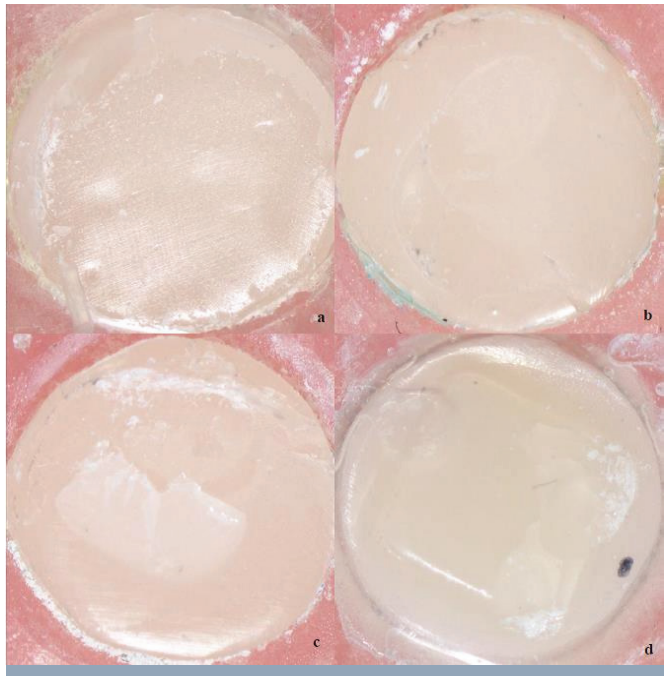

Figure 3. Stereomicroscope images of ceramic specimens
RARI score 0 (a); RARI score 1 (b); RARI score 2 (c); RARI score 3 (d)
RARI, resin attachment remnant index

the use of an all-in-one universal bonding agent and a high-viscosity universal composite after air abrasion resulted in the highest SBS values for attachment bonding to LD ceramics.[17] Conversely, surface etching with Al_2O_3 abrasive particles is not recommended for LD ceramics because it produces extremely irregular surfaces that differ considerably from those produced by acid etching.[18]

A self-etching ceramic primer (MEP), which allowed for etching and silanization in one step, was used in this study, considering the advantages of eliminating the toxic potential of acid etching and minimizing the technique sensitivity of conventional methods. Only silanization can be used to achieve adhesion in glass ceramics, but it is insufficient for zirconia ceramics.[19] Because zirconia has glass-free components, the formation of surface roughness cannot be provided by HFA etching, as occurs in LD ceramics. Therefore, the MZ ceramics were sandblasted to enhance micromechanical retention, although a self-etching ceramic primer (MEP) was used. Conventional pretreatment of the LD and MZ ceramics was performed using HFA etching and sandblasting, respectively, followed by silane application. As the manufacturer advised the use of the aligner composite with G-Premio Bond for bonding of aligner attachments, this universal adhesive was applied to improve the bond strength between pretreated ceramic surfaces and aligner composite.[20]

According to the SBS results, the adhesion between the silane agents and the universal adhesive provided relatively high bond strength with one exception. The LD ceramics pretreated with HFA etching and the universal primer had the lowest bond strength. This result is quite close to the lower bound of the adequate bond strength value reported by Reynolds.[21] Compared with the conventional pretreatment, the MEP increased the bond strength of the LD ceramics. These findings can be explained by the technical sensitivity of the acid etching procedure. HFA etching with a 5% acid concentration and a short application time (20 seconds) was preferred in this study. Ramakrishnaiah et al.[22] reported that etching for a short time produced small pores, whereas etching for a long time

Table 3. The RARI scores of study groups

Groups	RARI scores					p[a]
	0 (%)	1 (%)	2 (%)	3 (%)	4 (%)	
Group 1 (LD+HFA+MP)	5 (50)	5 (50)	0 (0)	0 (0)	0 (0)	0.491
Group 2 (MZ+S+MP)	3 (30)	4 (40)	2 (20)	1 (10)	0 (0)	
Group 3 (LD+MEP)	3 (30)	7 (70)	0 (0)	0 (0)	0 (0)	
Group 4 (MZ+S+MEP)	3 (30)	6 (60)	1 (10)	0 (0)	0 (0)	

[a]Chi-square test
p<0.05: statistically significant.
LD, lithium disilicate; HFA, hydrofluoric acid etching; MP, monobond plus (universal primer); MEP, monobond etch & prime (self-etching primer); MZ: monolithic zirconia; S: sandblasting

produced wide irregular grooves. Previous studies have also discovered a positive correlation between surface roughness and etching time.[22-24] Prolonged etching time and high acid concentration may increase the SBS of aligner attachments prepared on LD specimens. The application of 9.6% HFA etching for 60 s was recommended for orthodontic attachment adhesion to ceramic surfaces in a recent review.[25] Asiry et al.[26] reported that conventional pretreatment produced higher SBS values for LD ceramics than self-etching primer. This difference could be due to the acid remnants in the deep porosities of the non-neutralized ceramic surfaces.[27] Similarly, Canay et al.[28] recommended the removal of precipitates that interfere with the bonding mechanism. However, in this study, the acid-etched LD surfaces were rinsed thoroughly to eliminate residuals without additional application. This resulted in the self-etching primer increasing the bond strength of the aligner attachments bonded to the LD ceramics.

The SBS results also revealed that the sandblasted zirconia ceramics had similar bond strengths after silanization with either the universal or self-etching primer. In this context, it should be emphasized that both ceramic primers had the same silanization component. In line with these findings, Gutierrez et al.[29] reported that the use of MDP-containing silane and an MDP-containing universal adhesive for bonding to air-abraded zirconia resulted in more stable results after thermocycling. It is worth noting that the detachment forces decrease after thermocycling.[6,26,30] In this study, the number of cycles was set to 1,000 because the aging procedure was performed, with follow-up visits that were required every four to six weeks being considered. However, this period could be accepted as short-term aging because 10,000 cycles correspond to approximately one year of aging.[31] In contrast, the sandblasted MZ ceramics that were pretreated with the universal primer had a mean SBS value that exceeded the surface damage threshold value reported in the literature (>13 MPa).[30] Therefore, it was necessary to assess the ceramic surfaces after detachment because of the risk of surface damage with or without remnant adhesives caused by high bond strength.[25] In this case, the RARI was developed and used for evaluation and scoring.

According to the RARI scores, the amount of resin attachment remaining on the ceramic surfaces was almost similar, with no statistically significant differences. However, it is worth noting that the higher the bond strength, the greater the remnant resin.[14,26] Consistent with these findings, the conventional pretreatment of LD ceramics with HFA etching demonstrated relatively lower RARI scores in parallel with lower SBS values. In addition, greater bond strength and more attachment remnants were found in MZ ceramics when the pretreatment was performed using universal primer after sandblasting. Under these circumstances, a tungsten carbide bur must be used along with subsequent reglazing or repolishing to eliminate the remaining resin attachments on the ceramic surfaces.[32] Moreover, the detachment that occurs at the ceramic and resin interface could increase the risk of ceramic damage. In this study, no surface damage was observed regardless of the ceramic type and the large detachment forces. In other words, silane application provided surface protection for all groups.

Study Limitations

Based on the SBS and RARI results of this study, the null hypothesis was partially rejected. The self-etching primer produced a significantly higher SBS for the LD ceramics than the universal primer. The major limitation of this study was the difficulty in interpreting the findings in terms of clinical conditions. Another limitation was the interpretation of the findings based on previous bracket bonding studies. Furthermore, this study is the first one on aligner attachment bonding to different ceramics using a self-etching primer, and there is no study on a precise method for determining remnant aligner attachment. Therefore, the developed RARI scoring system is expected to be used in future studies when different bonding protocols are tested under both *in vitro* and *in vivo* conditions.

CONCLUSION

Compared with conventional pretreatment with the universal primer, pretreatment with a self-etching ceramic primer increased the bond strength of the LD ceramics. A self-etching ceramic primer can be used for aligner attachment bonding to LD and MZ ceramics.

Ethics

Ethics Committee Approval: Ethical approval is not applicable because this study does not include any studies with human or animal subjects.

Informed Consent: Informed consent is not applicable because this study does not include any studies with human subjects.

Author Contributions: Concept - S.Ç., R.N., S.H.A., F.A.; Design - S.Ç., R.N., S.H.A., F.A.; Supervision - S.Ç., R.N., S.H.A., F.A.; Fundings - S.Ç., R.N., S.H.A., F.A.; Materials - S.Ç., R.N., S.H.A., F.A.; Data Collection and/or Processing - S.Ç., R.N., S.H.A., F.A.; Analysis and/or Interpretation - S.Ç., R.N., S.H.A.; Literature Review - S.Ç., R.N., S.H.A.; Writing - S.Ç., R.N., S.H.A.; Critical Review - S.Ç., R.N., S.H.A.

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