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Evaluation of shear bond strength of metallic and ceramic brackets bonded to enamel prepared with self-etching primer

Tancan Uysal, Ayca Ustdal and Gokmen Kurt
Department of Orthodontics, Faculty of Dentistry, Erciyes University, Kayseri, Turkey

SUMMARY The aim of this *in vitro* study was to evaluate the shear bond strength (SBS) of different metallic and ceramic bracket bonding combinations using self-etching primers (SEPs). Eighty freshly extracted human premolar teeth were randomly divided into four equal groups for bonding with ceramic or metallic brackets as follows: group 1, metallic brackets bonded with conventional acid etching; group 2, metallic brackets bonded with Transbond Plus Self-Etching primer (TPSEP); group 3, ceramic brackets bonded as per group 1; group 4, ceramic brackets bonded as per group 2. The SBS of these brackets was measured and recorded in megapascals (MPa). The adhesive remnant index (ARI) scores were determined after bracket failure. Data were analyzed with the analysis of variance, Tukey, and chi-square tests.

The bond strength of group 3 (mean: 36.7 ± 11.8 MPa) was significantly higher than group 4 (mean: 26.6 ± 8.9 MPa; $P < 0.05$), group 1 (mean: 25.5 ± 5.1 MPa; $P < 0.01$), and group 2 (mean: 22.9 ± 7.3 MPa; $P < 0.001$). No significant differences in debond locations were found among the groups ($P > 0.05$). Compared with conventional acid etching, SEPs significantly decreased the SBS of ceramic orthodontic brackets.

Introduction

Ceramic brackets were introduced because of increasing aesthetic demands from orthodontic patients (Verstrynge *et al.*, 2004). Since their introduction, product design and clinical performance has greatly improved and the superior aesthetics of ceramic brackets and the resistance to discolouration are well accepted. However, increased frictional resistance (Kusy and Whitley, 1990; Bednar *et al.*, 1991), a higher risk of enamel fracture during debonding (Jeiroudi, 1991; Redd and Shivapuja, 1991), has limited their use. A third generation of ceramic brackets, Clarity, was introduced in 1997; this bracket had a metal-lined archwire slot and a vertical slot designed to help create a consistent bracket failure mode during debonding (Bishara *et al.*, 1997). This type of bracket was thought to combine the aesthetic advantages of ceramics and the functional advantages of metallic brackets.

The acid-etch technique is commonly used in orthodontics for bonding brackets. For bonding application, phosphoric acid is recommended for composite resin adhesives and poly-acrylic acid etching for resin-modified glass ionomer cements (Sfondrini *et al.*, 2001); however, both these etching techniques require rinsing and air drying. To simplify orthodontic bonding, self-etching primer (SEP) systems, which combine acid etching, rinsing, and priming (Romano *et al.*, 2005) reduce the clinical steps and result in a saving in chair-side time, because the procedure requires only air drying after application. According to White (2001), SEPs are easy to manipulate and use, resulting in greater patient comfort and a decrease in chair time by 65 per cent. In recent years, a new SEP, Transbond Plus Self-Etching Primer (TPSEP), was developed especially for orthodontic bonding. It includes methacrylated phosphoric acid esters, which function both as an etching agent and primer before bonding. TPSEP has been experimentally tested in several *in vitro* studies (Sfondrini *et al.*, 2001; Buyukyilmaz *et al.*, 2003; Ireland *et al.*, 2003) and revealed promising adhesive bonding results (Buyukyilmaz *et al.*, 2003; Ireland *et al.*, 2003).

With metallic brackets, the critical question for the clinician is whether the bond is too weak to withstand the forces applied during orthodontic treatment. With ceramic brackets, the concern is whether the bond is too strong for safe debonding (Bishara, 2000). Because ceramic brackets do not bend during debonding, fractures of the composite or the cohesive force between the bracket and adhesive system may occur (Verstrynge *et al.*, 2004). Debonding forces fracture the ceramic bracket or the adhesive system at the tooth/resin surface, which often creates cracks in susceptible enamel.

In a laboratory study, Bishara *et al.* (2001) evaluated the use of a SEP for orthodontic bracket bonding and found that SEPs produced lower but clinically acceptable shear bond strength (SBS) than the conventional acid-etching method. SEPs may be useful in reducing the bond strength of ceramic brackets, thus minimizing possible enamel fractures at debonding.

The aim of this *in vitro* study was to evaluate the SBS of different metallic and ceramic bracket bonding combinations using SEPs. For the purpose of this study, the null hypothesis assumed that there were statistically significant differences between (1) SBS values and (2) the site of bond failure of metallic and ceramic brackets bonded to enamel prepared using TPSEP or the conventional-etching method.

Materials and methods

Local ethical committee approval for the study was granted by Erciyes University.

Eighty healthy human mandibular premolars recently extracted for orthodontic purposes were used in this research. The criteria for tooth selection included no caries or cracks, no pre-treatment with a chemical agent such as alcohol, formalin, or hydrogen peroxide, or any other form of bleaching. Their buccal surfaces were intact, and they had not been subjected to any type of treatment.

The teeth were stored in distilled water for 1 month and the water was changed weekly to avoid bacterial growth. The roots of these teeth were placed vertically in a self-cure acrylic and the crowns were exposed avoiding contact between the resin and tooth. The buccal surfaces were pumiced, washed with a spray, and dried with compressed air before enamel preparation.

To compare the materials, the samples were randomly divided into four equal groups. The brackets were then bonded according to the following protocols by the same operator (TU).

Group 1: Thirty seven per cent phosphoric acid gel (Ventura Gel Acondicionador, Madespa, Spain) was applied to the enamel for 15 seconds and the teeth were then rinsed with a water spray for 30 seconds and air dried for 20 seconds. After surface preparation, a liquid primer, Transbond XT (3M Unitek, Monrovia, California, USA), was applied to the etched surface and left uncured. Standard edgewise premolar metallic brackets (slot 0.022 inch; 3M Unitek) with a base surface area of 12 mm^2 were bonded to the teeth, according to the manufacturer's recommendations.

Group 2: TPSEP (3M Unitek) was gently rubbed onto the enamel surface for approximately 3 seconds with the disposable applicator supplied with the system. A moisture-free air source was then used to deliver a gentle burst of air to the enamel. Standard edgewise premolar metallic brackets (3M Unitek) were bonded using a standard protocol.

Group 3: This group was treated the same as group 1, except that ceramic brackets (Clarity™, metal-reinforced ceramic bracket, slot 0.022 inch, 3M Unitek) were bonded to the teeth. The average surface of the orthodontic bracket base of 14.54 mm^2 was obtained from the manufacturer's reports.

Group 4: The enamel in this group was prepared the same as group 2, except that ceramic (Clarity, 3M Unitek) brackets were bonded by the standard protocol.

All metallic and ceramic brackets were bonded to the teeth with Transbond XT light cure adhesive, according to the manufacturer's instructions. Excess resin was removed with an explorer before polymerization. A quartz-tungsten halogen light unit (Hilux 350, Express Dental Products, Toronto, Canada) with a 10 mm diameter light tip was then used for 40 seconds to cure the specimens (20 seconds from the mesial and 20 seconds from the distal). The specimens were then stored in distilled water at 37°C for 24 hours before SBS testing.

Debonding procedure

The embedded specimens were secured in a jig attached to the base plate of a universal testing machine (Hounsfield Test Equipment, Salford, Lancashire, UK). A chisel-edge plunger was mounted in the movable crosshead of the testing machine and positioned to allow a shear force to be applied to the enamel–resin interface. A crosshead speed of 0.5 mm/minute was used, and the maximum load necessary to debond the bracket was recorded. The force required to debond the brackets was measured in Newton (N), and the SBS [1 megapascals (MPa) = 1 N/mm^2] was then calculated by dividing the force values by the bracket base area.

Residual adhesive

After debonding, all teeth and brackets were evaluated at ×10 magnification using a microscope (5240, Olympus, Tokyo, Japan) by one operator (AU) who was blinded to group allocation to determine the adhesive remnant index (ARI; Årtun and Bergland, 1984; Oliver, 1988) scores. The ARI scores were used as a more comprehensive means of defining the sites of bond failure between the enamel, resin, and bracket base.

Statistical methods

All statistical analyses were performed using the Statistical Package for Social Sciences for Windows 13.0, (SPSS Inc., Chicago, Illinois, USA). The Shapiro–Wilks normality test and Levene's variance homogeneity test were applied to the bond strength data. The data showed normal distribution, and there was homogeneity of variances between the groups. Descriptive statistics including mean, standard deviation, minimum, and maximum values were calculated for each test group. Comparisons of the mean SBS values were made with analysis of variance (ANOVA). Multiple comparisons were undertaken using Tukey honestly significant difference (HSD) test. The chi-square test was also used to determine significant differences in ARI scores among the four groups.

Results

SBS

The descriptive statistics for each group are presented in Table 1. The results of the ANOVA revealed statistically significant differences in bond strength among the four groups ($F = 7.408$, $P < 0.001$). Thus, the first null hypothesis of this study was not rejected. The Tukey HSD test showed that the bond strengths of group 3 (ceramic + acid etching, mean: 36.7 ± 11.8 MPa) were significantly greater than group 1 (metallic + acid etching, mean: 25.5 ± 5.1 MPa; $P < 0.01$), group 2 (metallic + TPSEP, mean: 22.9 ± 7.3 MPa; $P < 0.001$), and group 4 (ceramic + TPSEP, mean: 26.6 ± 8.9 MPa; $P < 0.05$).

Table 1 Descriptive statistics and the results of analysis of variance (ANOVA) and Tukey honestly significant difference tests comparing shear bond strengths of the four groups tested. Group 1, metal bracket + acid etching; group 2, metal bracket + TPSEP; group 3, ceramic bracket + acid etching; group 4, ceramic bracket + TPSEP.

Groups	N	Mean (MPa)	Standard deviation	Min	Max	ANOVA, $F = 7.408$	Multiple comparison		
						P value	Group 2	Group 3	Group 4
Group 1	20	25.5	5.1	17.0	34.0	***	NS	**	NS
Group 2	20	22.9	7.3	9.0	34.0			***	NS
Group 3	20	36.7	11.8	22.0	58.0				*
Group 4	20	26.6	8.9	14.0	40.0				

N indicates sample size; min, minimum; max, maximum; NS, not significant; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

ARI

The amount of residual adhesive on the enamel surface as evaluated by the ARI is given in Table 2. No statistically significant differences were observed among the groups tested (chi-square value = 16.857, $P = 0.155$). Therefore, the second null hypothesis of this study was rejected. In all groups, there was a higher frequency of ARI scores of 2–4, which indicated that some amount of adhesive was left on the tooth surface and bracket base. These failures were mostly at the resin–resin interface.

Table 2 Modes of failure in the four groups (group 1, metal bracket + acid etching; group 2, metal bracket + TPSEP; group 3, ceramic bracket + acid etching; group 4: ceramic bracket + TPSEP) after shear bond testing evaluated using the adhesive remnant index (ARI).

Groups	N	ARI scores					Chi-square value	Significance
		1	2	3	4	5		
Group 1	20	1	6	3	1	4	16.857	NS, $P = 0.155$
Group 2	20	1	8	2	1	3		
Group 3	20	3	5	1	5	1		
Group 4	20	3	2	1	7	2		

NS, not significant; ARI scores: 1 = all of the composite, with impression of bracket base, remained on tooth; 2 = more than 90 per cent of composite remained; 3 = more than 10 per cent but less than 90 per cent of composite remained on tooth; 4 = less than 10 per cent of composite remained on tooth surface; 5 = no composite remained on enamel.

Discussion

Adult patients demand high-quality orthodontic treatment with ceramic brackets, but some clinicians remain concerned about their bond strength. A review of the literature failed to identify any study that had investigated the effect of the SBS of ceramic orthodontic brackets bonded to enamel prepared with TPSEP.

In an *in vitro* study, Olsen *et al.* (1996) investigated the effect of varying etching times on the bond strength of ceramic brackets and suggested that a clinically useful bond strength can be achieved by decreasing etching time from 30 to 10 seconds. Their findings supported previous studies which concluded that clinically acceptable bond strengths could be obtained with etching times as short as 15 seconds (Carstensen, 1986; Wang and Lu, 1991; Olsen *et al.*, 1996). Thus, a 15 second etching time was used in the current study.

SEPs were introduced in order to reduce the steps required for attaching orthodontic brackets as well as reducing chair time, thus improving comfort for both patients and clinicians (White, 2001). This quick and simplified technique has become very popular. SEPs should, according to the manufacturer's instructions, be used together with Transbond XT composite to achieve the best adhesive result. In this study, TPSEP was used before bonding ceramic brackets with its original composite, Transbond XT. When compared with phosphoric acid, TPSEP produces a uniform and more conservative etching pattern, with regular adhesive penetration and less aggressive enamel demineralization (Verstrynge *et al.*, 2004). It can be inferred from previous laboratory investigations that TPSEP can be used successfully to bond orthodontic brackets, in conjunction with phosphoric acid used with Transbond XT primer (Viazis *et al.*, 1990; Bednar *et al.*, 1991).

Varying SBS values for ceramic brackets have been reported in the literature. Earlier studies indicated that ceramic brackets with a silane-treated chemical base had significantly higher mean bond strengths than metallic brackets that ranged between 18.8 and 28.3 MPa (Joseph and Rossouw, 1990). Mundstock *et al.* (1999) reported that the mean bond strength of metal-reinforced brackets was significantly lower than that of conventional ceramic brackets but comparable with metallic brackets. Third generation ceramic brackets are collapsible. The mean SBS range of these brackets has been reported to be between 10.4 and 15.6 MPa and were similar to those of second generation ceramic brackets (Bishara *et al.*, 1997; Mundstock *et al.*, 1999). Ødegaard and Segner (1988) reported bond strengths of 23.0 ± 5.3 and 20.7 ± 5.0 MPa when debonding ceramic brackets bonded with mix and no-mix adhesives, respectively. Bishara *et al.* (1993) found a bond strength value of 10.9 ± 3.3 MPa. Although several authors have tried to reduce bond strengths by changing the adhesives, etchants, or etching times, no consistent methods have been found that would apply to all types of ceramic brackets (Chaconas *et al.*, 1991).

In the present study, the SBS of orthodontic brackets bonded to enamel that had been prepared using the SEP systems or the conventional acid-etching method were evaluated and higher SBS ranges than the values reported in the literature were found. Group 3 showed values of 22.0–58.0 MPa (mean: 36.7 ± 11.8 MPa) and group 4 of 14.0–40.0 MPa (mean: 26.6 ± 8.9 MPa). Ceramic brackets bonded with the conventional acid-etching method showed the highest bond strength values than all other combinations. Although it is not clear why Transbond XT produced significantly higher bond strengths than the reported values, the type of adhesive resin may influence the clinical bond strength of an orthodontic bracket to enamel (Meguro *et al.*, 2006).

Many studies have demonstrated that when SEPs are used, the degree of penetration by the adhesive to the etched enamel is less when compared with that of conventional acid etching. The more deeply the enamel surface is penetrated by the adhesive, the greater the penetration of the adhesive and the greater risk of damage to the enamel (Yap *et al.*, 2004). The present results support the findings of Yap *et al.* (2004) that the use of SEPs significantly decreases SBS values when compared with conventional acid etching for bonding ceramic brackets.

Reynolds (1975) suggested that a minimum bond strength of 5.9–7.8 MPa is adequate for routine clinical use. All bond strength values of the brackets used in this study were greater than this minimum requirement and within clinically acceptable ranges. Ceramic orthodontic brackets bonded with TPSEP showed similar bond strength values as metallic brackets bonded with conventional acid etching. However, clinical conditions such as the variability of heat and humidity of the oral cavity may significantly differ from an *in vitro* setting.

The sites of failure within the bracket–resin–enamel complex can occur within the bracket, between the bracket and the resin, within the resin, and between the tooth surface and the resin. Bond failure at the bracket–resin interface or within the resin is more desirable than at the resin–enamel interface, because enamel fracture and cracking have been reported during bracket debonding especially with ceramic brackets (Bishara *et al.*, 1997). Earlier reports showed that metallic brackets consistently failed at the resin–bracket base interface, whereas ceramic brackets with chemically retained bases primarily failed at the resin–enamel interface (Joseph and Rossouw, 1990). For mechanically retained brackets, the most common failure site was the bracket–resin interface, and, on average, more than 50 per cent of the resin remained on the teeth after debonding (Forsberg and Hagberg, 1992). ARI scores in the present study were predominantly 2–4 in all groups, and the differences in ARI scores did not reach statistical significance. The mode of failure was thus at the resin–resin interface, resulting in a decrease in the risk of enamel fracture. Although higher bond strength values were obtained with TPSEP in the ceramic bracket group compared with the metallic bracket group, acceptable ARI scores were also recorded for the single-step self-etching adhesive. This is desirable because of the reduced risk of damage or fracturing of the enamel during debonding of ceramic brackets.

Conclusion

In the present study, the aim was to minimize possible enamel fracture risks at the debonding stage, by reducing bond strength values of ceramic brackets by changing the enamel-conditioning method. Bearing in mind the shortcomings of an *in vitro* setting, the results of this laboratory study showed:

1. The use of SEPs for conditioning enamel in the bonding of ceramic orthodontic brackets significantly decreased the SBS values compared with the conventional acid-etching method.
2. Although bonding brackets to enamel prepared with TPSEP or the conventional method did not significantly alter the site of failure, ceramic brackets bonded with SEP can be beneficial due to the bond failure location occurring generally between the resin–resin interface.

Address for correspondence

Dr Tancan Uysal
Erciyes Universitesi
Dis Hekimligi Fakultesi
Ortodonti AD
Melikgazi
Kayseri 38039
Turkey
E-mail: tancanuysal@yahoo.com

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