# Bond strength of ceramic brackets bonded to enamel with amorphous calcium phosphate-containing orthodontic composite

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SUMMARY The aim of this *in vitro* study was to compare the shear bond strength (SBS) and failure modes of a conventional resin-based composite with a recently developed amorphous calcium phosphate (ACP)containing orthodontic composite system. Forty freshly extracted human maxillary premolar teeth were randomly divided into two equal groups. Conventional composite (group 1; Transbond-XT®; 3M Unitek) and ACP-containing orthodontic composite (group 2; Aegis-Ortho®; Harry J. Bosworth Co.) were used for bonding ceramic orthodontic brackets. The SBS of these brackets were measured and recorded in megapascals (MPa). Adhesive remnant index (ARI) scores were determined after bracket failure. Data were analysed with a Student's *t*-test for two independent variables and Pearson's chi-square tests.

Statistical analysis showed that the bond strength of group 1 (mean:  $36.7\pm6.8$  MPa) was significantly higher than group 2 (mean:  $24.2\pm5.4$  MPa; *P*<0.01). Although a greater percentage of the fractures were cohesive at the composite interface (Score 1 + Score 2=70 per cent in group 1 and 90 per cent in group 2), statistically significant differences were observed between the groups (*P*<0.05). The ACP system is suitable for bonding ceramic orthodontic brackets due to the lower SBS values compared with conventional composite. The ACP-containing composite is recommended for use in clinical orthodontic practice in order to achieve lower decalcification scores under ceramic orthodontic brackets.

# Introduction

White spot lesions are not only unaesthetic but they may also become irreversible and lead to lesions. For these reasons, white spot lesions are of concern to orthodontists, and advancements in orthodontic adhesive materials serve as one possible avenue to prevent this occurrence (Foster *et al.*, 2008).

Schumacher et al. (2007) developed a biologically active restorative material that may stimulate the repair of tooth structure through the release of components, including calcium and phosphate. This material contains amorphous calcium phosphate (ACP) as the bioactive filler encapsulated in a polymer binder (Skrtic et al., 2003, 2004a; Antonucci and Skrtic, 2005). ACP has the properties of both a preventive and a restorative material that justify its use as a dental sealant, composite, and more recently, an orthodontic adhesive. ACPfilled composite resins have been shown to recover 71 per cent of the lost mineral content of decalcified teeth (Antonucci and Skrtic, 2005). One ACP-containing composite, Aegis Ortho (Harry J. Bosworth Co., Skokie, Illinois, USA), has been marketed for use as a light-cured orthodontic composite with similar properties to previously used resins. These materials encourage the formation of hydroxyl-apatite, which in turn can be used by the tooth for remineralization (Skrtic et al., 1996). This can be maintained for a considerable time, offering a promising antagonist to demineralization, and can promote the prevention of future white spots throughout orthodontic treatment (Skrtic *et al.*, 2004b).

With metal brackets, the critical question for the clinician was whether the bond was too weak to withstand the forces applied during orthodontic treatment. With ceramic brackets, the concern was whether the bond was too strong for safe debonding (Bishara, 2000). Since ceramic brackets do not bend during debonding, it is necessary to break the adhesive force of the composite or the cohesive force between the bracket and adhesive system (Verstrynge *et al.*, 2004). Debonding forces can break the ceramic bracket or the adhesive system at the tooth/resin surface, which often creates cracks in susceptible enamel. Although attempts have been made to reduce the shear bond strength (SBS) of ceramic brackets by changing the composites, the etchants, or the etching times, no consistent methods have been found that would apply to all types of ceramic brackets (Chaconas *et al.*, 1991).

Recently, the remineralization potential (Skrtic *et al.*, 2003; Antonucci and Skrtic, 2005) and bond strengths (Dunn, 2007; Foster *et al.*, 2008) of ACP-containing materials used either with metallic bracket or lingual retainer composite (Uysal *et al.*, 2009b) have been investigated. In an *in vitro* study, Dunn (2007) concluded that metallic brackets bonded to teeth with an ACP-containing composite material failed at significantly lower forces than those bonded with an orthodontic resin-based

composite. Uysal *et al.* (2009b) reported significantly lower SBS values for Aegis Ortho when used as a lingual retainer composite. The aim of this study was to reduce the SBS values of ceramic brackets by changing the composite type, using a newly introduced composite, for minimizing the possible enamel fracture risks during debonding and to compare the SBS and failure modes of a conventional composite with a recently developed ACPcontaining orthodontic composite system. The null hypothesis assumed that there were no statistically significant differences between (1) the SBS and (2) the site of bond failure of ceramic brackets bonded to enamel either with a conventional composite or with an ACPcontaining orthodontic composite system.

### Materials and methods

Forty human maxillary premolars were used in this study. All teeth were newly extracted for orthodontic reasons and presented no caries, cracks, or fissures. The criteria for tooth selection dictated 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 orthodontic or endodontic treatment.

Immediately after extraction, the teeth were cleaned of any residual tissue tags, washed under running tap water and stored in distilled water, which was changed weekly to avoid bacterial growth. The roots of the teeth were placed vertically in a self-cure acrylic resin so that the crowns were exposed, avoiding contact between the resin and crown. The buccal surfaces were cleaned and polished with a rubber cup and slurry with pumice and water, then rinsed with a water spray and finally dried with compressed air.

The enamel surfaces were acid etched with phosphoric acid gel (35 per cent acid etch; Harry J. Bosworth Co.) for 30 seconds, rinsed for 15 seconds with sterile water from an air/water syringe, and dried with oil- and moisture-free air. In all etched cases, a frosty white appearance of the enamel was present. Ceramic brackets (Clarity<sup>™</sup>, metal-reinforced ceramic bracket, 0.022 inch slot; 3M Unitek, Monrovia, California, USA) were bonded to the teeth using the bonding protocols recommended by the manufacturer. The average surface of the orthodontic bracket base according to the manufacturer was 14.54 mm<sup>2</sup>.

Group 1 (control group): Transbond XT® (3M Unitek) primer was applied to the etched surface in a thin film and left uncured. Transbond XT® (3M Unitek) composite paste was applied to the bracket base, and the bracket was positioned on the tooth and pressed firmly into place. The excess composite was removed from around the bracket with a scaler.

Group 2: A thin layer of ACP-containing orthodontic composite (Aegis Ortho; Harry J. Bosworth Co.) was applied to the etched enamel. A thin layer of the composite was also applied to the base of the ceramic bracket and immediately pressed into the composite on the tooth surface.

Following the manufacturer's recommendations, excess composite was not removed.

A quartz tungsten halogen light unit (Hilux 350; Express Dental Products, Toronto, Canada) with a 10 mm diameter light tip was used for curing the specimens from the mesial and distal for 10 seconds each (total time 20 seconds). The specimens were then stored in distilled water at 37°C for 24 hours before bond strength testing.

#### Debonding procedure

After completing the procedures, 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 so that the leading edge was aimed at the enamel/composite 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 remove the brackets was measured in Newtons (N), and the SBS (1 MPa=1 N/mm<sup>2</sup>) was then calculated by dividing the force values by the bracket base area (14.54 mm<sup>2</sup>).

#### Residual adhesive

After debonding, all teeth and brackets were examined under  $\times 10$  magnification (SZ 40; Olympus, Tokyo, Japan). The amount of adhesive remaining on the enamel surface was coded using the criteria proposed in the adhesive remnant index (ARI) of Årtun and Bergland (1984):

0=no adhesive remains on the tooth surface

1 = less than half the adhesive remains on the tooth surface 2 = more than half the adhesive remains on the tooth surface 3 = all the adhesive remains on the tooth surface.

#### Statistical methods

All statistical analyses were performed with the Statistical Package for Social Sciences (SPSS for Windows 13.0; SPSS, Chicago, Illinois, USA). Descriptive statistics, including the mean, standard deviation, minimum and maximum values, were calculated for the two groups. Shapiro–Wilks normality and Levene's variance homogeneity tests were applied to the SBS data. The data showed normal distribution, and there were homogeneity of variances among the groups. A Student's *t*-test was used to compare the SBS data of the two composites. Fracture modes were analysed using a Pearson's chi-square test. Significance was predetermined at P < 0.05.

# Results

The descriptive statistics for each group are presented in Table 1. The mean difference between the SBS of groups 1 and 2 was -12.5 MPa, 95 per cent confidence interval, t=3.749, df=28, and P=0.001. The results of the Student's *t*-test for independent samples revealed statistically significant differences in bond strength between the two groups (P<0.01). Thus, the first null hypothesis was rejected. Statistical testing showed that the SBS of group 1 (mean:  $36.7\pm6.8$  MPa) was significantly higher than that of group 2 (mean:  $24.2\pm5.4$  MPa).

The failure modes of the specimens are shown in Table 2. Although a greater percentage of the fractures were cohesive at the composite interface (Score 1 + Score 2=70 per cent in group 1 and 90 per cent in group 2), statistically significant differences were found between the groups (P < 0.05). Therefore, the second null hypothesis of this study was rejected. A significant difference in ARI scores was observed between the groups.

# Discussion

Many adult patients demand high quality orthodontic treatment with the use of ceramic brackets. On the other hand, many clinicians complain about the side effects of these brackets because of their higher bond strength. However, a review of the literature indicated that no research had been published that evaluated and compared the effect of the SBS of ceramic orthodontic brackets bonded with ACP composite.

The development and incorporation of ACP materials in dentistry is an alternative approach to reverse the effects of

 Table 1
 Descriptive statistics and *t*-test results of the bond strength comparison of the two composites tested.

Groups tested	п	Bond	strength (N	Significance		
		Mean	Standard deviation	Minimum	Maximum	
Transbond XT ACP-containing composite	20 20	36.7 24.2	6.8 5.4	22.0 16.0	48.0 34.0	**( <i>P</i> <0.01)

 Table 2
 Modes of failure after shear bond testing using the adhesive remnant index (ARI).

Groups tested	Ν	ARI sc	Significance			
		0	1	2	3	
		n (%)	n (%)	n (%)	n (%)	
Transbond XT ACP-containing composite	20 20	4 (20) 2 (10)	6 (30) 15 (75)	8 (40) 3 (15)	2 (10) 0 (0)	*(P<0.05)

demineralization on enamel surfaces. Only a few articles have investigated the incorporation of calcium phosphates into orthodontic composites. Sudjalim et al. (2007) evaluated the effects of sodium fluoride (NaF) and 10 per cent casein phosphopeptide (CPP)-ACP on enamel demineralization adjacent to orthodontic brackets and found that application of CPP-ACP, NaF, or CPP-ACP/NaF can significantly prevent enamel demineralization when orthodontic composite resin is used for bonding. Recently, investigations related to a available orthodontic commercially **ACP-containing** composite were performed. Dunn (2007) and Foster et al. (2008) compared the SBS of metallic orthodontic brackets bonded to enamel using ACP-containing composite with that of brackets bonded with a conventional resin-based orthodontic composite and found low but acceptable bond strengths. The present results support the previous findings that the use of ACP-containing composite significantly decreases SBS values when compared with that of a conventional composite.

It should be noted that the SBS range for the ACPcontaining composite (16.0–34.0 MPa) was lower than that of the Transbond XT® group (22.0–48.0 MPa), perhaps due to its lower maximum bond strength. This may partly account for its low standard deviation (Table 1). Nonetheless, the ACP-containing composite produced a consistent bond.

Reynolds (1975) suggested that a minimum bond strength of 5.9–7.8 MPa is adequate for bonding brackets. Tavas and Watts (1984) reported that shear/peel strengths of direct bonded adhesives should develop to 4 kg in 5 minutes and 6 kg in 24 hours. The SBS values of the different brackets used in this study were greater than this minimum requirement and were therefore within clinically acceptable ranges. Ceramic orthodontic brackets bonded with Aegis-Ortho® showed a lower bond strength than those bonded with Transbond XT®. These lower SBS values for ceramic brackets were considered acceptable. However, clinical conditions may differ significantly from an *in vitro* setting. Clinically, composites are subject to stresses, temperature fluctuations, variable electrolytes, microorganisms, and other factors that may affect their performance.

The sites of failure within the bracket-resin-enamel complex may occur within the bracket itself, between the bracket and the resin, within the resin, and between the tooth surface and the resin. Bond failure at the bracketresin interface or within the resin is more desirable than at the resin-enamel interface because enamel fractures and cracks have been reported during bracket debonding especially with ceramic brackets (Bishara et al., 1997). Earlier reports on the bond failure site showed that metal 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). In the present study, ARI scores were predominantly 1–2 in the subgroups, but the differences were statistically significant. These scores indicate that the mode of failure was primarily at the resin–resin interface, and the risk of enamel fracture is therefore decreased. The results of this study showed that, although higher bond strength values were obtained in the Transbond XT® group compared with those in the ACP-containing composite group, acceptable ARI scores were recorded for both composites. This can be desirable because of less damage or fracturing of the enamel during debonding of ceramic brackets.

ACP-containing composite may be an adjunct in the prevention of white spot lesions especially where compliance is lacking. Uysal *et al.* (2009a) recommended the use of ACP-containing orthodontic composite for any at-risk orthodontic patient because they found that using ACP-containing orthodontic composite for bonding orthodontic brackets successfully inhibited caries *in vitro*.

The findings of the present study suggest that ACPcontaining composite can provide a lower but suitable bond strength to at least one orthodontic composite and minimally meet the bond strength recommendations of different authors (Reynolds, 1975; Tavas and Watts, 1984). Future *in vivo* studies, examining the efficacy of these composites in preventing white spot lesions, appear warranted.

# Conclusion

Bearing in mind the shortcomings of an *in vitro* setting, it was concluded that:

- 1. ACP-containing Aegis-Ortho® composite resulted in a significant decrease in bond strength of ceramic orthodontic brackets to etched enamel surface. However, all bond strength values were within clinically acceptable ranges.
- 2. Although bonding brackets to enamel prepared with ACP-containing composite or a conventional method did not significantly alter the site of failure, ceramic brackets bonded with ACP-containing composite can be beneficial due to the bond failure location occurring generally between the resin–resin interface during debonding resulting in less damage to the enamel.

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