Original Article

Bond Strength of Amorphous Calcium Phosphate–Containing Orthodontic Composite Used as a Lingual Retainer Adhesive

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ABSTRACT

Objective: To evaluate the shear bond strength and fracture mode difference between amorphous calcium phosphate (ACP)–containing adhesive and conventional resin-based composite material used as an orthodontic lingual retainer adhesive.

Materials and Methods: Forty crowns of extracted lower human incisors were mounted in acrylic resin, leaving the buccal surface of the crowns parallel to the base of the molds. The teeth were randomly divided into two groups: experimental and control, containing 20 teeth each. Conventional lingual retainer composite (Transbond-LR, 3M-Unitek) and ACP-containing orthodontic adhesive (Aegis-Ortho) were applied to the teeth surface by packing the material into the cylindrical plastic matrices with a 2.34-mm internal diameter and a 3-mm height (Ultradent) to simulate the lingual retainer bonding. For shear bond testing, the specimens were mounted in a universal testing machine, and an apparatus (Ultradent) attached to a compression load cell was applied to each specimen until failure occurred. The shear bond data were analyzed using Student's *t*-test. Fracture modes were analyzed by χ^2 test.

Results: The statistical test showed that the bond strengths of group 1 (control Transbond-LR, mean: 24.77 $\pm$ 9.25 MPa) and group 2 (ACP-containing adhesive, mean: 8.49 $\pm$ 2.53 MPa) were significantly different from each other. In general, a greater percentage of the fractures were adhesive at the tooth-composite interface (60% in group 1 and 55% in group 2), and no statistically significant difference was found between groups.

Conclusion: The ACP-containing Aegis-Ortho adhesive resulted in a significant decrease in bond strength to the etched enamel surface. (*Angle Orthod.* 2009;79:117–121.)

KEY WORDS: Bond strength; Amorphous calcium phosphate; Lingual retainer

INTRODUCTION

Bonded lingual retainers are now effective devices for long-term retention.[1] Bonded lingual retainers are fabricated in various designs, which consist of a combination of different wires in different sizes bonded with different composites.[1] The demineralization pattern under and around the composite is particularly important in orthodontics, especially for lingual retainer adhesives, as they are exposed to the oral cavity and are intended to serve in the mouth for a long period.

Årtun[2] investigated the potential caries and periodontal problems associated with long-term use of different types of bonded lingual retainers and concluded that, regardless of the type of wire involved in construction of the 3-3 retainers, there is a tendency for plaque and calculus to accumulate along the retainer wires, and this tendency seems to increase with time. Årtun and Brobakken[3] also indicated that this plaque accumulation often promotes subsequent acid production leading to demineralization and an alteration in the appearance of the enamel surface.

To prevent demineralization or white spot lesions, research has focused mainly on protocols for fluoride

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intervention. Forsten[4] emphasized the importance of fluoride usage during orthodontic treatment to prevent development of white spot lesions. Usually, the fluoride is applied as solutions, pastes, or varnishes aiming at the whole dentition.[4] The anticariogenic and remineralizing effects of the long-acting fluoride release from conventional glass ionomer cements (GICs) can be predicted, and there are also indications of a similar effect by resin-modified glass ionomer cements (RMGICs). Despite the advantages of conventional GICs and RMGICs, they have some shortcomings with respect to orthodontic bonding. One study reported poor shear bond strength with GICs, in the range of 2.4 to 5.5 MPa, with either phosphoric or polyacrylic acid to condition the enamel surface before bonding.[5] GICs also have higher detachment rates than composite resin systems.[6]

In a recent study, Schumacher et al[7] developed biologically active restorative materials that may stimulate the repair of tooth structure through the release of cavity-fighting components including calcium and phosphate. They contain amorphous calcium phosphate (ACP) as bioactive filler encapsulated in a polymer binder.[8–10] Calcium and phosphate ions released from ACP composites, especially in response to changes in the oral environment caused by bacterial plaque or acidic foods, can be deposited into the tooth structures as an apatite mineral, which is similar to the hydroxyapatite found naturally in teeth.[11]

ACP has the properties of both a preventive and restorative material that justify its use in dental cements, sealants, composites, and, more recently, orthodontic adhesives. ACP-filled composite resins have been shown to recover 71% of the lost mineral content of decalcified teeth.[11] One ACP-containing adhesive, Aegis-Ortho (The Bosworth Co, Skokie, Ill), has been marketed for use as a light-cured orthodontic adhesive with similar properties to previously used resins. These materials are encouraging to the formation of hydroxyapatite, which can be used by the tooth for remineralization.[12] This important condition can be maintained for a considerable time, offering a promising antagonist to demineralization, and it can promote the prevention of future white spots throughout orthodontic treatment.[13]

Studies have demonstrated the remineralization potential[9,11,14] or bracket bond strengths of ACP-containing materials,[13,15] but no studies have been performed to investigate their bond strength as an orthodontic lingual retainer adhesive. The aim of this in vitro study was to compare the shear bond strength of a commercially available orthodontic adhesive containing ACP with a conventional resin-based orthodontic lingual retainer adhesive.

For the purposes of this study, the null hypothesis assumed that there were no statistically significant differences in (1) bond strength and (2) failure site location values of composites bonded to enamel with an ACP-containing adhesive and a conventional lingual retainer adhesive system.

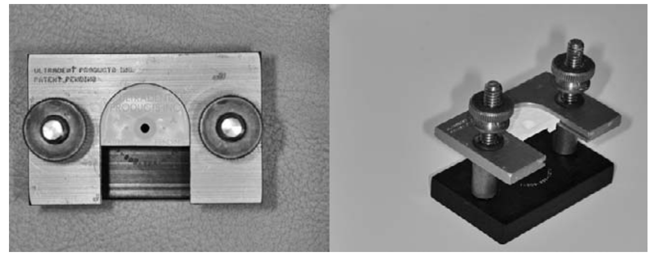

Figure 1. Application apparatus (Ultradent) of composite on the enamel surface.

MATERIALS AND METHODS

Mandibular incisors extracted for periodontal reasons were stored in distilled water. Teeth with hypoplastic areas, cracks, or gross irregularities of the enamel structure were excluded from the study. The criteria for tooth selection dictated no pretreatment with a chemical agent such as alcohol, formalin, hydrogen peroxide, and so forth. Soft tissue remnants and calculus were removed from the teeth, following which they were cleaned with a fluoride-free pumice and rubber cup.

Forty teeth were selected. The roots of the teeth were cut off with a water-cooled diamond disk, and the crowns were mounted in a 3-cm-diameter circle mold using chemically cured acrylic resin (Vertex, Zeist, the Netherlands). The teeth were distributed into two groups: one experimental and one control, each containing 20 teeth. A 37% orthophosphoric acid gel (3M Dental Products, St Paul, Minn) was used for the acid etching of the teeth for 15 seconds. The teeth were then rinsed with water for 15 seconds and dried with oil-free air for 10 seconds until a frosty white appearance of the etched enamel was observed.

Group 1 (Control): After enamel surface preparation, the liquid primer Transbond XT (3M Unitek, Monrovia, Calif) was applied to the etched surface and not cured according to the manufacturer's recommendation. An orthodontic lingual retainer composite resin (Transbond LR, 3M Unitek) was added to the middle part of tooth surface by packing the material into the cylindrical plastic matrices (Figure 1) with a 2.34-mm internal diameter and a 3-mm height (Ultradent, South Jordan, Utah).[16,17]

Group 2: ACP-containing orthodontic adhesive (Aegis-Ortho, Harry J. Bosworth Co, Skokie, Ill) was added to the etched enamel surface,[15] similar to

Table 1. Descriptive Statistics and Results of the *t*-Test Comparing the Bond Strength of the Two Groups Tested

Group Tested	n	Bond Strength, Mpa				Significance
		Mean	SD	Minimum	Maximum	
Transbond LR	20	24.77	9.25	11.63	44.2	$P < .001$
Amorphous calcium phosphate–containing adhesive	20	8.49	2.53	2.33	11.63	

Table 2. Modes of Failure After Shear Bond Testing[a]

Group Tested	n	Failures			Significance
		Adhesive	Cohesive	Mix	
Transbond LR	20	12 (60%)	1 (5%)	7 (35%)	NS, $P = .946$
Amorphous calcium phosphate–containing adhesive	20	11 (55%)	1 (5%)	8 (40%)	

[a] NS indicates nonsignificant.

group 1, by packing the material into cylindrical-shaped plastic matrices with an internal diameter of 2.34 mm and a height of 3 mm.

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 for 40 seconds. The specimens were then stored in distilled water at 37°C for 24 hours before bond strength testing.

Debonding Procedure

For shear bond testing, the specimens were mounted in a universal testing machine (Hounsfield Test Equipment, Salfords, UK). A notch-shaped apparatus (Ultradent) attached to a compression load cell at a cross-head speed of 0.5 mm/min was applied to each specimen at the interface between the tooth and composite until failure occurred. The maximum load (N) was divided by the cross-sectional area of the bonded composite posts to determine the bond strength in MPa.

Fracture Analysis

Fracture analyses were performed using an optical stereomicroscope (20× magnification; SZ 40, Olympus, Tokyo, Japan). Failures were classified as cohesive if more than 80% of the resin was found remaining on the tooth surface, adhesive if less than 20% of the resin remained on the tooth surface, or mixed if certain areas exhibited cohesive fracture whereas other areas exhibited adhesive fracture.

Statistical Analysis

Descriptive statistics, including the mean, standard deviation, and minimum and maximum values, were calculated for the two test groups. The Shapiro-Wilks normality test and the Levene variance homogeneity test were applied to the bond strength data. The data showed normal distribution, and there was homogeneity of variances between the groups. Student's *t*-test for two independent variables was used to compare the shear bond strengths of the two adhesives. Fracture modes were analyzed using a Pearson χ^2 test. The significance was predetermined at $P < .05$.

RESULTS

The descriptive statistics for each group are presented in Table 1. The results of the Student's *t*-test for independent samples revealed statistically significant differences in bond strength between the two groups tested ($P < .001$). Thus, the first null hypothesis of this study was rejected. The statistical test showed that the bond strength of group 1 (control-Transbond LR, mean: 24.77 ± 9.25 MPa) was significantly higher than the bond strength of group 2 (ACP-containing adhesive, mean: 8.49 ± 2.53 MPa).

The fracture patterns of the specimens are shown in Table 2. In general, a greater percentage of the fractures were adhesive at the tooth-composite interface (60% in group 1 and 55% in group 2), and no statistically significant differences were found between the groups ($P > .05$). Therefore, the second null hypothesis of this study failed to be rejected.

DISCUSSION

The development and incorporation of ACP materials in dentistry is a different approach to reversing the effects of demineralization on enamel surfaces.[15] The first commercially available ACP-containing materials were a sugar-free chewing gum containing casein phosphopeptide–amorphous calcium phosphate (CPP-ACP) and an ACP-containing toothpaste.[18] Shen et al[18] showed that CPP-ACP chewing gum resulted in a dose-related increase in enamel subsurface remineralization. This increased enamel remineralization was consistent with previous studies showing the anticariogenic and remineralization potential of CPP-ACP in solution.[19] Although there is a growing body of evidence to support ACP's remineralizing potential, there is concern over the physical properties of ACP-containing materials.

In the orthodontic literature, Sudjalim et al[20] evaluated the effects of sodium fluoride (NaF) and 10% 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, two investigations related to a commercially available orthodontic ACP-containing adhesive were performed and reported. Foster et al[13] and Dunn[15] compared the shear bond strength of orthodontic brackets bonded to enamel using adhesive containing ACP to that of brackets bonded with a conventional resin-based orthodontic adhesive and found low but satisfactory bond strength needed to function as an orthodontic adhesive.

In the current study, a different protocol[16,17] was used for shear testing compared with previous studies to simulate the lingual retainer bonding. This modification also eliminated some critical aspects of the testing protocols affecting the bond strength outcome. The bracket base design may contribute to the misalignment of load application during testing, making the bonding system prone to failure, introducing variations that depend on the stress gradients generated.[17] It has also been found that variability exists among the manufacturers with respect to the design or dimensions of the brackets in nominally identical prescriptions.[21] This inconsistency poses a significant problem in studies evaluating bond strength.[22] Because the thickness of the adhesive layer is very small and there is a tight interface between adhesive and bracket, the tips of the blades could not be accurately placed on it once the force was applied. The tips of the blades may deviate toward the interface between adhesive and bracket or adhesive and enamel, which may significantly affect the reliability of the results. Blunting of blades during use, particularly the pointed ones, would have increased the force level applied on later specimens.[17] For these reasons, we used only composite blocks to take pure bond strength values between enamel and composite to simulate the failure of the lingual retainer, detached between the composite-enamel interface.

Skrtic et al[9,11,14] demonstrated that ACP-containing composites can be made stronger by the addition of glass-forming agents and with silica or zirconia-hybridized ACP in Bis-GMA/ TEGDMA/HEMA/ZrDMA–based composites. Aegis-Ortho contains UDMA and DMA resins and a proprietary blend of fillers that also includes ACP. However, under the conditions of this in vitro study, the bond strength of the orthodontic composite to teeth with Aegis-Ortho adhesive was found to be significantly weaker than the bond strength with a conventional resin-based lingual retainer adhesive. Similar to the findings of Foster et al,[13] the bond strength range for the ACP-containing adhesive was lower than that of the other group, perhaps because of its lesser maximum bond strength; this may partially account for its low standard deviation. Nonetheless, the ACP-filled orthodontic adhesive showed a consistent bond strength result, an aspect desired by clinicians.

Reynolds[23] determined that the minimum bond strength values in direct orthodontic bonding systems that are clinically acceptable are 5.9–7.8 MPa. The bond strength values in the two groups in the present study compared favorably with those recommendations. However, clinical conditions may differ significantly from an in vitro setting. It needs to be emphasized that this was an in vitro study and that the test conditions have not been subjected to the rigors of the oral environment.[24] Heat and humidity conditions in the oral cavity are highly variable. Because of the differences between in vivo and in vitro conditions, as well as the testing method, a direct comparison cannot be made with the findings of other studies.

Most orthodontic bonding studies have shown a mix or cohesive-type failure.[25,26] In those studies, after bond strength testing, a part of the composite resin remained on either the enamel surface or the bracket base, causing cohesive failure rather than adhesive failure between the enamel and composite resin. Because brackets were not used in the present study, more adhesive failures occurred, and the actual bond strength between the enamel and composite could be measured. The higher percentage of adhesive failures also confirmed the accuracy of the bond strength method. Further clinical investigations are also required to test whether these ACP-containing composites can prevent or treat white spot lesions or dental caries during orthodontic treatment.

CONCLUSIONS

- The ACP-containing Aegis-Ortho adhesive resulted in a significant decrease in bond strength to the etched enamel surface.
- There was no evidence to suggest a statistical difference between the groups' failure characteristics.

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