

Bond strengths of different orthodontic adhesives after enamel conditioning with the same self-etching primer

Rogelio J. Scougall-Vilchis,* Chrisel Zárate-Díaz,† Shusuke Kusakabe⁺ and Kohji Yamamoto⁺

Department of Orthodontics, School of Dentistry, Autonomous University State of Mexico,* Private Practice, Toluca City, Mexico† and the Division of Oral Functional Sciences and Rehabilitation, School of Dentistry, Asahi University, Japan⁺

Aim: To determine the shear bond strengths (SBS) of stainless steel brackets bonded with seven light-cured orthodontic adhesives after the enamel was conditioned with the same self-etching primer.

Methods: A total of 140 extracted human molars were randomly divided into seven groups (N = 20). In all the groups, the enamel was conditioned with Transbond Plus SEP (TPSEP). Stainless steel brackets were bonded with the following orthodontic adhesives: Group I, Transbond XT; Group II, Blüglöo; Group III, BeautyOrtho Bond; Group IV, Enlight; Group V, Light Bond; Group VI, Transbond CC; Group VII, Xeno Ortho. The teeth were stored in distilled water at 37 °C for 24 hours and debonded with a universal testing machine. The modified adhesive remnant index (ARI) was also recorded.

Results: There were no significant differences in the SBS values among the groups: I (18.0 ± 7.4 MPa); II (18.3 ± 5.1 MPa); III (14.8 ± 4.3 MPa); IV (18.3 ± 7.0 MPa); V (16.4 ± 4.3 MPa); VI (20.3 ± 5.3 MPa); VII (15.9 ± 6.4 MPa), but significant differences in ARI were found.

Conclusions: The seven orthodontic adhesives evaluated in this study can be successfully used for bonding stainless steel brackets when the enamel is conditioned with TPSEP, however, the differences among some groups might influence the clinical bond strengths. In addition, the amount of residual adhesive remaining on the teeth after debonding differed among the adhesives. Further studies are required to better understand the differences in SBS and ARI.

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Rogelio J. Scougall-Vilchis: rogelio_scougall@hotmail.com

Chrisel Zárate-Díaz: chzd@yahoo.com

Shusuke Kusakabe: kusakabe@dent.asahi-u.ac.jp

Kohji Yamamoto: yamamoto.k@ray.ocn.ne.jp

Introduction

For more than 40 years researchers have been working to improve the bonding of orthodontic brackets to teeth. Recent developments have been the introduction of self-etching primers (SEP), originally intended for use in operative dentistry, to successfully bond orthodontic brackets.^{1–3} These primers cause less aggressive decalcification and less enamel loss than traditional phosphoric acid etchants, are less affected by humidity, prevent contamination with saliva and are quick to apply.^{3,4} It has also been reported that although these primers result in short enamel tags, brackets bonded after enamel

conditioning with SEPs have adequate shear bond strengths and, in many instances, less adhesive remains on the teeth after debonding.⁵ As a rule they are combined with a light-cured adhesive which enables brackets to be ‘tacked’ immediately in position.⁶

To our knowledge, Transbond Plus SEP (TPSEP) is the only SEP that does not significantly affect the shear bond strength (SBS) of orthodontic brackets.⁵ In light of the great diversity in ultrastructure, filler content, microhardness and chemical composition of different orthodontic adhesives,⁷ and the possibility that TPSEP may not behave favourably with all

Table I. Orthodontic adhesives used in this study.

Group	Orthodontic adhesive	Manufacturer
I	Transbond XT	3M Unitek, Monrovia, CA, USA
II	Blüglloo	Ormco Corp., Glendora, CA, USA
III	BeautyOrtho Bond	Shofu Inc., Kyoto, Japan
IV	Enlight	Ormco Corp., Glendora, CA, USA
V	Light Bond	Reliance Orthodontic Products, Itasca, IL, USA
VI	Transbond CC	3M Unitek, Monrovia, CA, USA
VII	Xeno Ortho	Dentsply-Sankin K.K., Tochigi, Japan

adhesives, we decided to determine the bond strengths of seven readily available light-cured orthodontic adhesives on the SBS of stainless steel brackets after the enamel was conditioned with TPSEP.

Materials and methods

One hundred and forty extracted human molars were collected and stored in a solution of 0.2 per cent (wt/vol) thymol to prevent bacterial growth, until required. The criteria for tooth selection included: molars with intact enamel surfaces, no white spot lesions and no history of orthodontic treatment or chemical treatment for bleaching.⁸ The teeth were rinsed with water and cleaned with a fluoride-free paste (Pressage, Shofu Incorporated, Kyoto, Japan) and rubber prophylactic cups (Message, Shofu Incorporated, Kyoto, Japan) in a slow-speed hand-piece. The teeth were then washed with water for 30 seconds and air-dried.

One hundred and forty stainless steel 0.018 inch, standard edgewise, upper incisor brackets (Tomy International, Tokyo, Japan) were used. The average surface area of the bases of 10 randomly selected brackets was 13.58 mm².

The teeth were randomly divided into seven groups (N = 20 per group). The buccal surface of each tooth was conditioned with TPSEP (3M Unitek, Monrovia, CA, USA) following the manufacturer's instructions.⁵ The TPSEP was rubbed on the enamel surface for 5 seconds then gently dried with compressed air for a few seconds.

The brackets were bonded with different light-cure orthodontic adhesives (Table I). Immediately after the brackets were placed, they were light-cured

Table II. Comparisons of the shear bond strengths of the adhesives.

Group	N	Mean (MPa)	SD	Range
I Transbond XT	20	18.0	7.4	8.3 - 34.9
II Blüglloo	20	18.3	5.1	11.3 - 30.5
III BeautyOrtho Bond	20	14.8	4.3	7.8 - 21.0
IV Enlight	20	18.3	7.0	7.6 - 30.5
V Light Bond	20	16.4	4.3	5.4 - 31.0
VI Transbond CC	20	20.3	5.3	9.0 - 26.7
VII Xeno Ortho	20	15.9	6.4	5.8 - 27.1

ANOVA, $p > 0.05$

(BlueLex, Yoshida Dental, Tokyo, Japan) for a total of 20 seconds (10 seconds on the mesial edge of the bracket and 10 seconds on the distal edge). All procedures were performed by the same researcher.

SBS test

After bonding, a short length of 0.017 x 0.025 inch stainless steel wire was ligated into each bracket slot to reduce deformation of the bracket during debonding. The teeth were embedded in acrylic resin and mounted in the universal testing machine (EZ Graph, Shimadzu, Kyoto, Japan) with the labial surfaces parallel to the debonding force.

An occluso-gingival load was applied to each bracket, producing a shear force at the bracket – tooth interface. This was accomplished with the flattened end of a steel rod attached to the crosshead of the universal testing machine. The SBS was measured at a crosshead speed of 0.5 mm/min and the load applied at fracture was recorded in newtons (N) and converted to megapascals (MPa) by dividing the load by the mean area of the bracket bases (13.58 mm²). Following debonding, the teeth were stored in distilled water at 37 °C for 24 hours.⁹

Modified adhesive remnant index

The enamel surface of each molar was inspected at x10 magnification and the amount of residual adhesive remaining on the surface of the tooth scored with the modified ARI: 1, all composite remained on the tooth; 2, more than 90 per cent of the composite remained on the tooth; 3, between 10 and 90 per cent of the composite remained on the tooth; 4, less than 10 per cent of the composite remained on the tooth; 5, no composite remained on the tooth.¹⁰

Table III. Distributions and percentages of adhesive remaining on the teeth after debonding.

Group	N	Modified ARI scores				
		Count (Per cent)				
		1	2	3	4	5
I Transbond XT	20	0 (0)	0 (0)	10 (50)	5 (25)	5 (25)
II Blüglöo	20	0 (0)	3 (15)	9 (45)	6 (30)	2 (10)
III BeautyOrtho Bond	20	2 (10)	9 (45)	9 (45)	0 (0)	0 (0)
IV Enlight	20	0 (0)	2 (10)	8 (40)	7 (35)	3 (15)
V Light Bond	20	0 (0)	2 (10)	8 (40)	8 (40)	2 (10)
VI Transbond CC	20	0 (0)	4 (20)	11 (55)	5 (25)	0 (0)
VII Xeno Ortho	20	8 (40)	7 (35)	5 (25)	0 (0)	0 (0)

$\chi^2 = 81.82$; $df = 24$, $p = 0.0001$

Statistical analysis

The SBS data were compared with a one-way ANOVA and post-hoc Scheffe tests. The significance in both tests was predetermined at $p < 0.05$. The distributions of ARI scores were compared with a chi-squared test.

Results

The SBS values and the descriptive statistics are presented in Table II. The mean SBS in all the groups exceeded 14.8 MPa and there were no statistically significant differences between the groups (ANOVA: $p > 0.05$). Groups I (Mean: 18.0 ± 7.4 MPa), II (Mean: 18.3 ± 5.1 MPa), and IV (Mean: 18.3 ± 7.0 MPa) had comparable mean values of SBS followed by Groups V (Mean: 16.4 ± 4.3 MPa) and VII (Mean: 15.9 ± 6.4 MPa). Group VI (Mean: 20.3 ± 5.3 MPa) had the highest mean value and Group III (Mean: 14.8 ± 4.3 MPa) the lowest mean SBS.

The ARI scores are given in Table III. The distributions of adhesive remnants in the groups were significantly different ($p = 0.0001$). The smallest amounts of adhesive remnant were found in Group I with a mean ARI score of 3. This group also had the highest number of teeth with a score of 5 and no teeth with scores of 1 or 2. Groups II, IV, V and VI showed comparable ARI scores, with mean scores of 3. More than 90 per cent of the composite remained on the buccal surfaces (ARI: 2) of between 10 and 15 per cent of the teeth in these groups, but no tooth had an ARI score of 1. The teeth in Group VII followed by Group III had the highest amount of adhesive left on the tooth after debonding: 40 per cent and 10 per

cent, respectively. In these groups there were no teeth with scores of 4 or 5.

Discussion

The SBS values for all TPSEP – composite combinations exceeded the range of values (6–8 MPa) considered by some researchers to be a suitable SBS for routine clinical use.^{11,12} Stainless steel brackets can be successfully bonded with any of the seven adhesives we investigated after the enamel is conditioned with TPSEP. However, we found different patterns of adhesive fracture during debonding that may influence the choice of adhesive.

In orthodontic practice, a reliable bond between the brackets and enamel is essential,¹³ but as the appliances are temporary, methods that avoid damage to the enamel during bonding and following debonding are desirable.^{14,15} Self-etching primers for enamel conditioning avoid the decalcification characteristic of phosphoric acid-based agents.¹⁶ They provide a 'gentler' etch pattern, which has been illustrated in several SEM studies.^{4,8,17} We selected TPSEP for enamel conditioning because it is frequently used in orthodontics,¹⁸ and brackets bonded to teeth conditioned with TPSEP had significantly higher SBSs than those bonded after the application of other SEPs.^{5,19} When different SEPs were used with the same composite resin we found TPSEP – resin was the only combination that did not affect the bond strength significantly compared to the control group etched with 37 per cent phosphoric acid for 15 seconds.¹⁹ When TPSEP was applied for only 3 seconds and the brackets debonded after 24 hours,

the orthodontic brackets presented higher SBS values than those in which the enamel had been etched with 37 per cent phosphoric acid.⁹ Furthermore, TPSEP has also been shown to provide higher 6-month survival rates than brackets bonded after a conventional acid etch.²⁰ Moreover, it has been shown to provide a suitable bond strength even if it is contaminated with saliva.²¹ A recent study reported that activated TPSEP stored for up to 15 days did not significantly affect the SBS of orthodontic brackets.¹⁸

The direct bonding of molar tubes is now a common procedure in orthodontic practice. In spite of the fact that the buccal surfaces of human molars have complex and variable shapes, the seven adhesives we evaluated yielded higher SBSs than considered adequate to accomplish treatment.^{11,12} Although we found there were no significant differences between the TPSEP – adhesive combinations, thermal stresses can significantly reduce the bond strength of TPSEP and a longer study may have disclosed differences between the groups.²² The SBS was variable in Groups I, IV, and VII: findings that are consistent with a previous study in which the enamel was conditioned with TPSEP and the brackets were bonded with Transbond XT.⁵ Groups I (Transbond XT), II (Blüglöo), and IV (Enlight) had approximately the same mean SBS values. A larger mean difference (slightly >5 MPa) was found between Groups VI (Transbond CC: 20.3 MPa) and III (BeautyOrtho Bond: 14.8 MPa). An interesting finding was the higher SBS value in Group VI (Transbond CC) when compared with Group I (Transbond XT). As Transbond CC is a fluoride-releasing adhesive, we expected a lower SBS value than that obtained with Transbond XT, but there was no significant difference between the two resins. The concentration of fluoride in Transbond CC did not appear to influence the bond strength of the resin under the conditions in our study.

As ceramic brackets have higher bond strengths than stainless steel brackets, an adhesive with a low SBS, such as BeautyOrtho Bond or Xeno Ortho, may be preferable to adhesives with high bond strengths.^{20,23} The bond strengths of stainless steel and ceramic brackets can be raised by treating the bracket pad with a silicone product and altered by using a different etchant or by applying a caries-protective resin after etching.^{25–27} Light Bond demonstrated slightly higher SBS than Transbond XT when the enamel was

etched with phosphoric acid,²⁶ and Blüglöo presented lower shear peel bond strength than Transbond XT.²⁷ Light Bond had a significantly higher SBS than both Transbond XT and Blüglöo after a caries protective sealant was applied.²⁷ With the combinations of TPSEP and resins we used, procedures that increase the SBS appear to be unnecessary as the bond strength values exceeded those considered to be appropriate for most clinical procedures, but there may be some advantages if the site of failure occurs at the resin – enamel interface.

Although frequently used, the ARI is a problematic parameter and the results should be regarded cautiously. It has been demonstrated that the amount of adhesive remaining on the tooth tends to be larger when a high SBS value is obtained.^{5,28} However, our findings are slightly contradictory as significantly more adhesive was found in the groups with low SBS values (Groups VII and III). In these groups, bracket failure frequently occurred at the bracket – adhesive interface. Pretreatment that enhances the visibility of the resin flash or the bond strength at the resin – bracket interface might reduce the amount of adhesive left on the tooth after debonding and/or the amount of time spent removing resin remnants.²⁴ A colouring agent in the resin flash has been tried.²⁹

With improvements in the physical and mechanical properties of composite resins, removing the adhesive remnants after debonding has become a clinical problem. Resin remnants may discolour over time and retain plaque.³⁰ Tooth cleaning is easier and faster and iatrogenic damage during cleaning is less likely to occur when brackets fail at the enamel – resin interface.^{5,10,31} However, bond failure at the bracket – adhesive interface or within the adhesive is considered to be safer than failure at the enamel – adhesive interface because enamel fracture can occur if failure occurs at the latter site.¹⁰

Apart from enamel fracture or gouges from injudicious use of hand instruments or burs, the enamel lost during orthodontic procedures is insignificant in terms of the total thickness of the enamel.³² Nevertheless, enamel loss at the time of bracket removal depends largely on the orthodontic materials used, the method of debonding, the tactile ability of the clinician and the instruments used.^{20,32} Least enamel loss occurs when TPSEP is used and the enamel cleaned with a slow-speed tungsten carbide bur.²⁸

Conclusions

Under the conditions of this in-vitro study, the following conclusions were drawn:

1. The seven orthodontic adhesives and TPSEP had SBS values that exceeded the range of values (6–8 MPa) considered by some researchers to be suitable for routine clinical use.
2. Stainless steel brackets can be successfully bonded with any of these adhesive pastes when the enamel is conditioned with TPSEP.
3. Less adhesive was found on the teeth when Transbond XT, Blüglöo, Enlight, Light Bond and Transbond CC were used.
4. Further in vivo and in-vitro studies are necessary to determine the effects of time on the shear bonding strengths and sites of fracture of the resin – TPSEP combinations we studied.

Corresponding author

Professor Rogelio J. Scougall-Vilchis
Department of Orthodontics
School of Dentistry
Autonomous University State of Mexico
Francisco Carbajal Bahena #241
Col. Morelos, Z.C. 50120
Toluca City
México
Tel: (+52) 722-280-91-13
Email: rogelio_scougall@hotmail.com

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