ORIGINAL ARTICLE

Effects of 3 adhesion promoters on the shear bond strength of orthodontic brackets: An in-vitro study

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Introduction: The objectives of this study were to (1) determine the effect of 3 adhesion promoters on shear bond strength and the amount of remnant adhesive on the teeth after debonding and (2) learn whether 1 promoter is material-specific, as stated by the manufacturer. **Methods:** The promoters tested were OrthoSolo (Ormco, Orange, Calif), All-Bond 2 (Bisco, Schaumburg, Ill), and Enhance L.C. (Reliance, Itasca, Ill). Two adhesives were used: Transbond XT (3M Unitek, Monrovia, Calif) and Light Bond (Reliance). One hundred fifty premolars were divided into 6 groups of 25, and brackets were bonded according to the manufacturers' instructions: (1) Transbond XT, (2) Transbond XT plus All-Bond 2, (3) Transbond XT plus OrthoSolo, (4) Transbond XT plus Enhance L.C., (5) Light Bond, and (6) Light Bond plus Enhance L.C. Bond strength was tested on a universal testing machine, and remnant adhesive was quantified with image analysis equipment. **Results:** The highest bond strength values were obtained when brackets were bonded with Light Bond plus Enhance L.C. These values were significantly higher than those achieved with Transbond XT, Transbond XT plus Enhance L.C., or Transbond XT plus All-Bond 2. Of the groups bonded with Transbond XT, the group that included OrthoSolo had the best results. **Conclusions:** None of the adhesion promoters significantly increased bond strength or the amount of adhesive remaining on the tooth after debonding. Enhance L.C. produced the greatest bond strength when used with the material-specific product Light Bond. (Am J Orthod Dentofacial Orthop 2006;129:390-5)

The words "adhesion promoters" were first used to designate molecules that adhered chemically to dental structures.[1] One of the first molecules tested was N-phenylglycine-glycidyl methacrylate, which was proposed by Bowen in 1965.[2] The first dentin adhesive was created with this molecule,[3] but commercial products showed poor clinical results.[4] Adhesion to the dentin was unsuccessful until the introduction of hydrophilic resins,[5] agents that promote adhesion to dentin.[6]

The incorporation of hydrophilic monomers to adhesive systems facilitates the infiltration of resin into the etched enamel, reducing interfacial porosity and therefore adhesive defects, achieving greater bond strength after polymerization.[7]

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Based on these concepts, adhesion promoters have been introduced in orthodontics. They incorporate hydrophilic resins as a component and are intended to improve bond strength and integrity. However, an increase in bond strength could compromise the safety of debonding.[8]

The objectives of this study were to (1) determine the effect of 3 adhesion promoters—OrthoSolo (Ormco, Orange, Calif), All-Bond 2 (Bisco, Schaumburg, Ill), and Enhance L.C. (Reliance, Itasca, Ill)—on the shear bond strength and the amount of remnant adhesive on the tooth after debonding brackets bonded with Transbond-XT adhesive system (3M Unitek, Monrovia, Calif.) and (2) learn whether Enhance L.C. is material-specific as stated by the manufacturer. For this reason, it was also used with the manufacturer's recommended adhesive—Light Bond (Reliance).

MATERIAL AND METHODS

One hundred fifty human maxillary premolars, without caries or fillings, were used. The teeth had been extracted for reasons unrelated to the objectives of this study and with the patients' informed consent. The project was approved by the University of Murcia Bioethical Commission.

The teeth were washed to remove any traces of blood and then placed in 0.1% thymol solution. They were stored in distilled water for up to 1 month; the water was changed periodically to prevent deterioration. Before testing, the teeth were set in a 4-cm long copper cylinder with an internal diameter of 3 cm, and the roots were set in type IV die stone.

The teeth were divided into 6 groups of 25, and metal maxillary premolar brackets (Victory Series, 3M Unitek) were bonded on their buccal surfaces, according to the manufacturers' instructions. The base area of each bracket was calculated (mean, 9.79 mm^2) by using image analysis equipment and MIP 4 software (Microm Image Processing Software, Digital Image Systems, Barcelona, Spain) under 400 times magnification. For all groups, the buccal surfaces were polished with a rubber cup and polishing paste (Détartrine, Septodont, Saint-Maur, France); then the area where the bracket was to be placed was etched with 37% *o*-phosphoric acid gel (Total Etch, Ivoclar, Vivadent, Schaan, Liechtenstein) for 30 seconds and washed with water. After washing, for groups 1, 3, and 5, the enamel surface was completely dried with compressed air; for groups 2, 4, and 6, the enamel was air-dried, leaving the surface slightly moist.

In group 1, 25 brackets were bonded with Transbond XT. A layer of Transbond XT primer was applied on the enamel, and Transbond XT paste was applied to the base of the bracket, which was then pressed firmly onto the tooth. Excess adhesive was removed around the base of the bracket, and the adhesive was light-cured with an Ortholux XT lamp (3M Unitek), positioning the light guide on each interproximal side for 10 seconds.

In group 2, 25 brackets were bonded with Transbond XT and Enhance L.C. adhesion promoter. Two layers of Enhance L.C. were applied; after the second layer, the surface was completely dried with compressed air until shiny. The bracket was immediately bonded with Transbond XT adhesive primer and paste.

In group 3, 25 brackets were bonded with Transbond XT and OrthoSolo adhesion promoter. A single layer of OrthoSolo was applied, and the bracket was bonded immediately (without air drying) with Transbond XT paste. According to the manufacturer, with light-cure systems, OrthoSolo takes the place of the primer.

In group 4, 25 brackets were bonded with Transbond XT and All-Bond 2 adhesion promoter. Five layers of All-Bond 2 (primers A + B) were applied; after the last layer, the surface was completely dried with compressed air to a shiny appearance. Immediately afterward, the bracket was bonded in place with Transbond XT primer and paste.

In group 5, 25 brackets were bonded with Light-Bond. A layer of Light-Bond liquid resin was applied and light-cured for 10 seconds. Light-Bond paste was applied to the base of the bracket, which was positioned on the tooth and pressed firmly. Excess adhesive was removed around the base of the bracket, and it was light-cured with the light guide positioned on the incisal side for 20 seconds and on the mesial side for 10 seconds.

In group 6, 25 brackets were bonded with Light Bond and Enhance L.C. adhesion promoter. After applying Enhance L.C. as in group 2, the brackets were bonded in position with Light-Bond adhesive system (primer and paste).

The specimens were immersed in distilled water at a temperature of 37°C for 24 hours.[9]

Shear bond strength was measured with a universal testing machine (Autograph AGS-1KND, Shimadzu. Japan) with a 1-kilonewton load cell connected to a metal rod with 1 end angled at 30°. The cross-head speed was 1 mm/minute.[9]

The teeth were set at the base of the machine so that the sharp end of the rod incised into the area between the base and the wings of the bracket, exerting a force parallel to the surface of the tooth in an occlusoapical direction. The force required to debond each bracket was registered in newtons (N), and converted into megapascals as a ratio of newtons to the bracket's surface area (MPa = N/mm2).

After debonding, the percentage of the surface of the bracket base covered by adhesive was determined with image analysis equipment (video camera connected to a microscope) and MIP 4 software. The percentage of the area still covered by adhesive on the tooth was obtained by subtracting the area of adhesion covering the bracket base from 100%. Then each tooth was assigned an adhesive remnant index (ARI) value according to the following criteria[10]: 0, no adhesive left on the tooth; 1, less than half the adhesive left on the tooth; 2, more than half the adhesive left on the tooth; 3, all adhesive left on the tooth.

Possible enamel fractures were also registered macroscopically.

Statistical analysis

The Kolmogorov-Smirnov normality test and the Levene variance homogeneity test were applied to the bond strength data. Because the data were not normally distributed, significant difference was evaluated ($P \leq .05$) by using the Kruskal-Wallis test, finding groups that were significantly different with the Mann-Whit-

Table I. Shear bond strength (MPa)

Group	*n*	*Mean*	*Median*	*SD*	*Minimum*	*Maximum*
Transbond XT[a]	25	12.27	11.3	5.01	6.79	28.01
Transbond XT plus Enhance L.C.[a]	25	12.67	12.26	2.7	8.99	20.01
Transbond XT plus OrthoSolo	25	14.52	14.61	3.17	8.53	22.5
Transbond XT plus All-Bond 2[a]	25	13.65	13.02	5.3	7.56	36.5
Light Bond	25	14.93	14.27	4.73	6.13	27.5
Light Bond plus Enhance L.C.[b]	25	16.97	16.29	5.55	6.64	32.4

Results were analyzed with Kruskal-Wallis and Mann-Whitney tests for 2 independent samples. Groups marked by different superscript letters showed significant differences. Groups without superscript letters had no significant differences with any other ($P \leq .003$).

ney test for 2 independent samples. To prevent an accumulation of errors from multiple comparisons, the significance level ($P \leq .05$) was modified by dividing it between the number of comparisons made (Bonferroni correction), and $P \leq .003$ was considered significant.

ARI values were analyzed by using the Pearson chi-square test and an analysis of corrected residuals. Both statistical tests were repeated, grouping the cases in categories with 0 and 1 index points or 2 and 3 points, to avoid having categories with an expected frequency lower than 5.

Enamel fractures were evaluated with the Pearson chi-square test and an analysis of corrected residuals.

A significance level of $P \leq .05$ was set for both the Pearson chi-square test and the analysis of corrected residuals (residual ≥ 2 implies $P \leq .05$).

The Kolmogorov-Smirnov test and the Levene homogeneity test of variances were applied to the data for the percentage area of adhesive remaining on the tooth. Because there was neither homogeneity of variances nor normal distribution, they were also analyzed with the Kruskal-Wallis test and the Mann-Whitney test for 2 independent samples, taking the Bonferroni correction into account.

The statistical analysis was made with the statistical program SPSS 10.0 for Windows (SPSS, Chicago, Ill).

RESULTS

The Kruskal-Wallis test showed significant differences ($P = .00$) in shear bond strength. The Mann-Whitney test for 2 independent samples established the differences between the system of greater bond strength with respect to the 3 systems that showed lower average values of bond strength: Light Bond plus Enhance L.C. and Transbond XT ($P = .001$), Light Bond plus Enhance L.C. and Transbond XT plus Enhance L.C. ($P = .001$), and Light Bond plus Enhance L.C. and Transbond XT plus All-Bond 2 ($P = .002$) (Table I).

The ARI values and enamel fractures are shown in Table II. The Pearson chi-square test indicated significant differences ($P = .00$) in ARI values, and the analysis of corrected residues showed that, although Transbond XT, Transbond plus Enhance L.C., and Transbond XT plus OrthoSolo were significantly associated (residual, 2.2, 4.3, and 3.2, respectively) with ARI scores of 2, Light Bond and Light-Bond plus Enhance L.C. were associated with ARI scores of 1 (residual, 4.6 and 5.3). Transbond XT plus All-Bond 2 was not significantly associated with any ARI score (Table II).

Both tests were repeated by grouping the ARI scores of 0 and 1, and 2 and 3; significant differences ($P = .00$) were obtained when the chi-square test was applied. A significant association for Transbond XT, Transbond XT plus Enhance L.C., and Transbond XT plus OrthoSolo (residual, 2.2, 4.3, and 3.2, respectively) was found in the "2 + 3" category, and for Light Bond and Light Bond plus Enhance L.C. in the "0 + 1" category (residual, 4.9 and 5.3). Transbond XT plus All-Bond 2 showed no significant associations (Table III).

Enamel fractures occurred in all groups except the Transbond XT-only group. Analysis of these fractures with the Pearson chi-square test did not show significant differences between the groups ($P = 0.4$). However, the analysis of corrected residues indicated a significant association between Transbond XT (residue = 2) and the absence of fractures.

The percentage of tooth area with adhesive remnant is shown in Table IV. The Kruskal-Wallis test detected significant differences between the various groups ($P = .00$). The Mann-Whitney test found these differences in the system that left a lower percentage of adhesive on the enamel: Light Bond plus Enhance L.C., with respect to Transbond-XT ($P = .000$), Transbond XT plus Enhance L.C. ($P = .000$), Transbond XT plus All-Bond 2, and Transbond XT plus OrthoSolo ($P = .000$). Significant differences were also observed in the second system that left a lower percentage of adhesive on the tooth: Light Bond, with respect to Transbond XT ($P = .000$), Transbond XT plus Enhance L.C ($P =$

Table II. ARI and enamel fractures

Group	n	ARI				Enamel fracture
		0	1	2	3	
Transbond XT	25	0	7	18[a]	0	0[b]
Transbond XT plus Enhance L.C.	25	0	1	20[a]	0	4
Transbond XT plus OrthoSolo	25	0	4	19[a]	0	2
Transbond plus All-Bond 2	25	0	9	12	0	4
Light Bond	25	1	20[a]	1	0	3
Light Bond plus Enhance L.C.	25	0	21[a]	0	0	4

ARI values were analyzed with Pearson chi-square test (obtaining significant differences) and analysis of corrected residuals. Superscript *a* indicates ARI value to which each group is associated significantly according to residuals analysis. [b]Indicates enamel fractures were evaluated with Pearson chi-square test without obtaining significant differences, but residuals analysis showed significant association for Transbond to nonproduction of fractures ($^{b,}P \leq .05$).

Table III. ARI values grouped into classes

Group	n	ARI	
		0 + 1	2 + 3
Transbond XT	25	7	18[a]
Transbond XT plus Enhance L.C.	21	1	20[a]
Transbond XT plus OrthoSolo	23	4	19[a]
Transbond XT plus All-Bond 2	21	9	12
Light Bond	22	21[a]	1
Light Bond plus Enhance L.C.	21	21[a]	0

ARI values were grouped into classes and evaluated with Pearson chi-square test (obtaining significant differences) and analysis of corrected residuals. Superscript *a* indicates class to which each group is associated significantly according to residuals analysis ($P \leq .05$).

.000), Transbond XT plus OrthoSolo ($P = .000$), and Transbond XT plus All-Bond 2 ($P = .003$).

DISCUSSION

It has been suggested that bond strength values between 5.9 and 7.8 MPa are sufficient for a clinically effective orthodontic bonding.[11] Greater bond strengths are sometimes required with uncooperative patients or fluoridated teeth, or when humidity control is difficult.

Enhance L.C. is an adhesion promoter for specific use in orthodontics. The manufacturer recommends application with adhesive systems from its product range. Thus, Enhance L.C. was used with a recommended system, Light-Bond, and a light-cured composite resin adhesive from another manufacturer (Transbond XT).

The bond strength provided by the Light Bond system was greater than the strength achieved with Transbond XT, but no significant differences were found between the systems.

Our results showed that Enhance L.C. produced a greater increase in bond strength for Light Bond than for Transbond XT, but the increase was not significant for either adhesive. Recent research has shown no significant increase in bond strength when Enhance L.C. was used with Light Bond on new brackets, but, when used on rebonded brackets, a reduction (although not significant) in bond strength occurred.[12] Enhance L.C. was already evaluated by applying it to the base of rebonded brackets, but this application produced no improvement in bond strength.[13]

Bond strength values with Light Bond were not significantly different from those of the other groups evaluated, but the bond strength achieved with Light Bond plus Enhance L.C. was significantly higher than that obtained with Transbond XT, Transbond XT plus Enhance L.C., and Transbond XT plus All Bond 2. These 3 systems had the lowest bond strengths of those evaluated.

The results from the ARI and the analysis of the percentage of tooth area with remnant adhesive showed that Enhance L.C. did not produce significant increases in the amount of adhesive remaining on the enamel. These results concur with previous research.[12]

It was also observed that Light Bond left significantly less adhesive on the enamel than Transbond XT after debonding, whether either system was used with Enhance L.C. This is an advantage because cleaning adhesive off teeth after debonding always causes some loss of enamel.[14]

The highest bond strength values were achieved with Light Bond plus Enhance L.C.; these values were significantly higher than those obtained with Transbond XT plus Enhance L.C. When greater bond strength is required, it might be preferable to use Enhance L.C. with Light Bond because less adhesive will remain on the teeth after debonding.

All-Bond 2 primer acts as an adhesion promoter in orthodontic bonding. However, no significant improvement in Transbond XT's bond strength was observed with All-Bond 2. All-Bond 2 does not increase the amount of remnant adhesive on the teeth; it reduces it, but not significantly. Chung et al[12] did not find an

Table IV. Percentage of tooth area covered by adhesive

Group	*n*	*Mean*	*Median*	*SD*	*Minimum*	*Maximum*
Transbond XT[a]	25	59.88	60.82	19.2	17	89
Transbond XT plus Enhance L.C.[a]	21	72.55	70.45	12	47	87
Transbond XT/OrthoSolo[a]	22	59.75	63.92	13.83	24	83
Transbond XT plus All-Bond 2[a]	21	50.82	58.68	24.24	19	84
Light Bond[b]	22	26.49	26.67	12.42	0	50
Light Bond plus Enhance L.C.[b]	21	26.23	26.03	11.45	8.5	50

Results were analyzed with Kruskal-Wallis and Mann-Whitney tests for 2 independent samples. Groups marked by different superscript letters showed significant differences ($P \leq .003$).

increase in the remnant adhesive when All-Bond 2 was used with Light Bond system. The use of All-Bond 2 did not significantly improve the bond strength of new brackets, but it did result in improvements for rebonded brackets, producing bond strengths that were comparable to those achieved with new brackets.[12] Woronko et al[15] observed that All-Bond 2 primer did not significantly affect the bond strength of composite resins to etched enamel.

OrthoSolo is an adhesion promoter that replaces the liquid resin in both light-cured composite and 2-paste adhesive systems. Although none of the promoters significantly increased bond strength with Transbond XT, and no significant differences were observed between Transbond XT plus OrthoSolo, Transbond XT plus All-Bond 2, and Transbond XT plus Enhance L.C., the bond strength of Transbond XT plus All-Bond 2 and Transbond XT plus Enhance L.C. was significantly less than Light Bond plus Enhance L.C. On the other hand, the adhesion of Transbond XT plus OrthoSolo did not differ significantly from the adhesion obtained with Light Bond plus Enhance L.C. Therefore, of the promoters tested with Transbond XT, OrthoSolo provided the best results and reduced the remnant adhesive (but not significantly) of Transbond XT.

The standard deviations and ranges for the bond strength values were wide in all groups (Table I). This variation might reflect the diversity in proper fit between the bracket base and the anatomically variable buccal curvature of the crowns.[12]

There is wide disparity among the various in-vitro studies (ie, types of teeth used, sample storage conditions before testing, machine head speed) that made it difficult to compare the bond strength values obtained for the different systems. The use of different units for bond strength measurements adds to the difficulty of comparing results. The force required to debond each bracket in our study was registered in newtons and converted into megapascals as a ratio of newtons to surface area of the bracket (MPa = N/mm^2). We think that, to properly compare different studies about bond tests in orthodontics, it is necessary to determine bond strength, because, when we use force of debond, we cannot compare brackets with different geometries.

Enamel fractures were produced in all groups, except when Transbond XT was used alone. Due to the risk of fractures, adhesion promoters are not recommended for patients with enamel defects.[16] The results suggest that fractures begin to occur when bond strength exceeds the threshold established by Transbond-XT system in our study. Although to make a suitable evaluation of enamel fractures and reach a valid conclusion, further research is required with a larger sample.

We must be cautious when extrapolating in-vitro results to the clinical situation. Many factors in the oral environment are impossible to reproduce in the laboratory. Clinical significance between bonding systems will be found only when oral strength conditions are between the corresponding values for the different systems evaluated. Obviously, if these oral strength conditions were usually above any of the adhesive systems, no clinical significance will be found regardless of the statistical significance among them. Therefore, in-vivo research must be carried out to confirm laboratory results.

CONCLUSIONS

1. No significant differences were found between Light Bond and Transbond XT bond strength. However, Light Bond left less adhesive on the teeth.
2. The greatest bond strength values were achieved with Light Bond plus Enhance L.C. These values were significantly greater than those achieved with Transbond XT alone or with either of the other adhesion promoters (Enhance L.C. or All-Bond 2).
3. Although no promoter significantly increased bond strength, it is preferable to use Enhance L.C. with Light Bond when greater bond strength is required. On the other hand, of the promoters tested with Transbond XT, OrthoSolo provided the best results.
4. Adhesion promoters do not significantly increase the adhesive remaining on the tooth after debonding.

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