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# Shear bond strength of orthodontic color-change adhesives with different light-curing times

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## ABSTRACT

**Background:** The purpose of this study was to evaluate the effect of light-curing time on the shear bond strength (SBS) of two orthodontic color-change adhesives (CCAs).

**Materials and Methods:** A total of 72 extracted premolars were randomly assigned into 6 groups of 12 teeth each. Subsequent to primer application, a metal bracket was bonded to the buccal surface using an orthodontic adhesive. Two CCAs (Greengloo and Transbond Plus) were tested and one conventional light-cured adhesive (Resilience) served as control. For each adhesive, the specimens were light-cured for two different times of 20 and 40 s. All the specimens underwent mechanical testing using a universal testing machine to measure the SBS. Adhesive remnant index (ARI) was used to assess the remnant adhesive material on the tooth surface. All statistical analyses were performed using SPSS software. The significance level for all statistical tests was set at $P \leq 0.05$.

**Results:** The SBSs of the tested groups were in the range of 14.05-31.25 MPa. Greengloo adhesive showed the highest SBS values when light-cured for 40 s, and Transbond Plus adhesive showed the lowest values when light-cured for 20 s. ARI scores of Transbond Plus adhesive were significantly higher than those of controls, while other differences in ARI values were not significant.

**Conclusion:** Within the limitations of his study, decreasing the light-curing time from 40 to 20 s decreased the SBS of the tested adhesives; however, this decline in SBS was statistically significant only in Transbond Plus adhesive

**Key Words:** Adhesive system, bond strength, dental adhesive, light curing, orthodontic bonding, shear bond strength

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## INTRODUCTION

Adhesives play an important role in orthodontics by bonding fixed appliances to tooth surfaces. A review of the long history of orthodontic bonding adhesives shows that many evolutional developments have occurred since the first chemically-cured composite resins to the most recently introduced light-cured color-change adhesives (CCAs).

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While chemically-cured composite resins have some shortcomings, such as incorporation of air bubbles during mixing and limitation in controlling the curing time accurately,[1,2] light-cured composite resins provide controlled polymerization time, more accurate bracket placement, and easier removal of excess adhesive prior to curing.[1,3]

However, there are still two major concerns about light-cured adhesives:

a. Improper removal of excess adhesive material from the tooth surface during bracket placement, which has been considered a potential risk for subsequent gingival irritation and white spot lesions on enamel surface;[4,5]
b. Restoring enamel, as closely as possible, to an intact and flawless surface after bracket removal.

To this end, all the adhesive material must be removed from the enamel surface, taking care to prevent removal of enamel. Similarity in shade and color makes it difficult to clearly delineate the enamel-adhesive interface, which may subsequently result in incomplete removal of the adhesive or loss of enamel during flash clean-up. Accordingly, a range of 5-150 µm has been reported in various studies for enamel loss.[6-9]

Color-change adhesives are a recent development in the world of orthodontic adhesives, with the purpose of facilitating the discrimination between the adhesive material and enamel. They provide a distinct color and contrast and can be easily differentiated from enamel during both bracket placement and adhesive removal.[5] CCAs are becoming popular among clinicians due to promising characteristics reported. Related studies have mostly demonstrated high bond strengths for CCAs under various conditions, suggesting that they can be used efficiently in orthodontic practice.[1,4,5,10-12]

Although a minimum of bond strength is required for any orthodontic bonding adhesive, a high bond strength may increase the risk of enamel fracture and pulp damage upon debonding.[5,10] A range of 6-8 MPa has been reported as the adequate bond strength for orthodontic purposes.[13,14] Enamel cracks appear when bond strength exceeds 13.5 MPa[15] or 14 MPa[16] and become more frequent as bond strength increases.[16-20] Since most of the studies on CCAs[4,5,10,12] have reported the shear bond strength (SBS) more than the safe upper limit, there is a demand to find ways to decrease it.

Some researchers have evaluated the effect of light-curing time on the SBS of orthodontic adhesives and concluded that the bond strength significantly decreases by reducing the curing time from 40 to 20 s.[1,21] However, the available literature lacks information about the effect of reducing light-curing time on bond strength of CCAs. Thus, the aim of this study was to evaluate the effect of different light-curing times on the SBS of two commonly used CCAs, i.e., Greengloo and Transbond Plus.

## MATERIALS AND METHODS

In this *in vitro* study, 72 recently extracted sound human upper premolar teeth without any caries, restorations or former root canal therapy were included. After removing residual periodontal tissues and debris, all the teeth were immersed in 5.25% NaOCl for 2 h and then stored in normal saline. Enamel surfaces were assessed under a stereomicroscope (DM143, Motic Digital Microscope) at ×4.5 magnification to detect cracks, calcifications or any other defects. Nonfluoridated pumice and rubber cups were used to clean the tooth surfaces. After mounting the specimens in auto-polymerizing acrylic resin, they were randomly assigned into 6 groups of 12 teeth each.

In Groups I and II, Resilience composite resin (Orthotechnology, FL, USA) was used as the adhesive material and cured for 20 and 40 s, respectively. In Groups III and IV, Greengloo composite resin (Ormco, Glendora, CA, USA) was used as the bonding adhesive and cured for 20 and 40 s, respectively. In Groups V and VI, Transbond Plus composite resin (3M, Unitek, Monrova, CA, USA) was applied as the adhesive with the curing time of 20 and 40 s, respectively.

Bonding procedure commenced as follows: In Groups I-IV, the buccal surfaces of the specimens were etched with 37% phosphoric acid gel (Ultradent, USA) for 30 s, rinsed with water, and dried with moisture-free air until a frosty white etched area was observed. In Groups I and II a thin layer of Resilience sealant resin (Orthotechnology, FL, USA) and in Groups III and IV Ortho Solo primer (Ormco, Glendora, CA, USA) were applied to the buccal surface and thinned by a gentle current of air. In Groups V and VI, Transbond Plus self-etching primer (3M, Unitek, Monrovia, CA, USA) was applied by an applicator to the buccal surface, and after 10 s thinned by a gentle current of air. For each specimen, the orthodontic adhesive was applied to the base of a 0.018” standard Edgewise metal bracket (Dentaurum, Ispringen, Germany). The bracket was placed on the buccal surface of the tooth and pressed firmly. Excess adhesive around the bracket was removed with a scaler. The adhesive was cured by a visible light-curing unit (Demetron LC, SDS Kerr, USA) at a light intensity of 800 mW/cm² from mesial and distal directions.

Subsequent to the completion of bonding procedure, all the specimens were stored in distilled water at 37°C for 24 h in a dark environment. Then, the specimens were mounted in the jig of a universal testing machine (Testometric, M350-10CT, England) with the long axis of the specimen parallel to the direction of the shear load. In order to apply the shear load, a blade measuring 0.3 mm in thickness was advanced at a rate of 1 mm/min until debonding occurred [Figure 1].

In this study, "debonding" was defined as the point at which a sharp and instantaneous drop >25% of the applied load occurred. This was usually accompanied by an audible crack. For each specimen, the load at debonding (measured in Newton) was recorded, and in order to calculate the SBS in MPa, it was divided by the surface area of the bracket base in millimeters.

The remnant adhesive material on the tooth surface was evaluated under a stereomicroscope at ×10 magnification and scored according to the modified adhesive remnant index (ARI).[22] In this five-point scale, score 1 represents the entire composite resin with an impression of the bracket base remaining on the tooth; score 2 represents more than 90% of composite resin remaining on the tooth; score 3 represents 10-90% of composite resin remaining on the tooth; score 4 represents <10% of composite resin remaining on the tooth; and score 5 represents no composite resin remaining on the tooth. Finally, the tooth surface was scrutinized under ×10 magnification for any postexperiment enamel fracture.

### Statistical analysis

One-way analysis of variance and Tukey honestly significant difference were used to compare the mean SBSs of the groups. Multiple comparison test was used to determine the significance of the differences in the ARI scores. All statistical analyses were performed using SPSS software (version 11; SPSS, Chicago, IL, USA). The significance level for all statistical tests was set at $P \leq 0.05$.

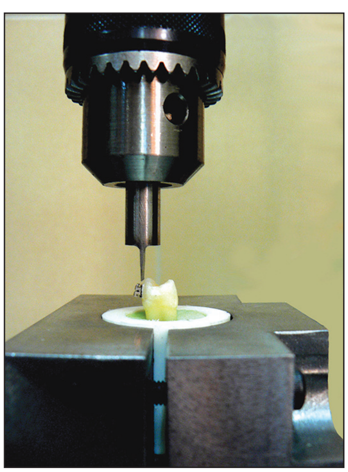

**Figure 1:** Measurement of shear bond strength of a specimen in a universal testing machine.

## RESULTS

Tables 1 and 2 present the mean SBSs of all the study groups and the significance of their differences. In all the three adhesives tested in this study, the mean SBS was lower when the specimens were light-cured for 20 s compared with the situation in which they were cured for 40 s; however, only the difference in Transbond Plus adhesive (Groups V and VI) was statistically significant ($P$ = 0.003). The highest SBS values were obtained in Group IV, in which Greengloo composite resin was cured for 40 s; and the lowest values were observed in Group V, in which Transbond Plus composite resin was cured for 20 s [Tables 1 and 2].

The remnant adhesive and the location of bond failure were scored according to ARI and the results are shown in Table 3. In none of the groups, debonding occurred at the bracket — adhesive interface. Totally, 88.8% of bond failures occurred in the adhesive layer (scores 2, 3 and 4) and 11.1% of debondings occurred at the enamel-adhesive interface with no adhesive remaining on the tooth. The most frequent bond failures at enamel-adhesive interface occurred in Groups V and VI with 25% and 33%, respectively [Table 3].

Multiple comparison test indicated significant differences between ARI scores of Transbond Plus

**Table 1: SBS values of all the study groups (MPa)**

| Group | Adhesive | Curing time (s) | SBS (mean ± SD) | Minimum | Maximum |
|---|---|---|---|---|---|
| I | Resilience | 20 | 17.24±3.48 | 12.58 | 21.86 |
| II | Resilience | 40 | 20.54±3.23 | 16.73 | 26.10 |
| III | Greengloo | 20 | 27.55±3.47 | 20.86 | 32.93 |
| IV | Greengloo | 40 | 31.25±2.43 | 26.92 | 34.73 |
| V | Transbond Plus | 20 | 14.05±4.24 | 8.73 | 23.37 |
| VI | Transbond Plus | 40 | 19.64±3.76 | 13.94 | 25.28 |

SBS: Shear bond strength; SD: Standard deviation.

**Table 2: Tukey HSD comparison of the mean SBSs among study groups**

| Groups | II | III | IV | V | VI |
|---|---|---|---|---|---|
| I | 0.201 | 0.000* | 0.000* | 0.234 | 0.544 |
| II | | 0.000* | 0.000* | 0.000* | 0.988 |
| III | | | 0.111 | 0.000* | 0.000* |
| IV | | | | 0.000* | 0.000* |
| V | | | | | 0.003* |

*Indicates statistically significant difference ($P \leq 0.05$); SBS: Shear bond strength; HSD: Honestly significant difference.

**Table 3: ARI scores of all the study groups**

| Group | Adhesive | Curing time (s) | ARI score | | | | | Total (*n*) |
|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | |
| I | Resilience | 20 | 0 | 3 | 6 | 3 | 0 | 12 |
| II | Resilience | 40 | 0 | 3 | 7 | 2 | 0 | 12 |
| III | Greengloo | 20 | 0 | 0 | 6 | 5 | 1 | 12 |
| IV | Greengloo | 40 | 0 | 2 | 4 | 6 | 0 | 12 |
| V | Transbond Plus | 20 | 0 | 0 | 2 | 7 | 3 | 12 |
| VI | Transbond Plus | 40 | 0 | 1 | 2 | 5 | 4 | 12 |
| Total (%) | | | 0 (0) | 9 (12.5) | 27 (37.5) | 28 (38.8) | 8 (11.1) | |

ARI: Adhesive remnant index.

and other groups. Based on the results of this test, the ARI scores of Group V were significantly higher than those of Group I. The ARI scores in Groups V and VI were significantly higher than those in Group II as well. Other differences were not statistically significant.

Stereomicroscopic evaluation revealed six postexperiment enamel fractures, 1 in Group II, 2 in Group III, and 3 in Group IV.

## DISCUSSION

Bond strength of orthodontic adhesives has been the subject of study for many researchers. The main purpose of these studies is to obtain optimal bond strength for orthodontic brackets, in which the bond is strong enough to prevent bracket debonding, and simultaneously weak enough to avoid enamel damage upon debonding. Bond strengths higher than 13.5 MPa[15] or 14 MPa[16] may result in enamel damage.

In this study, the SBS of the test groups ranged from 14.05 ± 4.24 MPa to 31.25 ± 2.43 MPa. It was shown that reducing the light-curing time from 40 to 20 s decreased the SBS in all the adhesives and the decrease was statistically significant in Transbond Plus adhesive; however, it seems that this decrease is not sufficient yet, since the mean SBSs were still more than the safe limit.[15,16] Thus, it may be of interest to evaluate lower light-curing times in future studies.

Türkkahraman *et al*.[12] measured the mean SBSs of four adhesives in the range of 16.0-22.1 MPa. Like the present study, they measured the highest SBS among CCAs in Greengloo and the lowest in Transbond Plus. Unlike the present study, the difference between the SBS of these CCAs was not statistically significant, while in the present study the SBS in Greengloo was significantly more than that in Transbond Plus. According to the manufacturer, higher bond strength of Greengloo is due to the sealant used in this adhesive, Ortho Solo, a fluoride-releasing universal sealant.[12] This sealant has a unique glass filler, which acts as a shock absorber and enhances bond strength by reducing the incidence of cracks that can lead to bond failure.[12] Chemical affinity of Greengloo for some metal brackets has also been mentioned as a useful factor in improving bond strength.[4] However, there are conflicting results about the bond-enhancing role of Ortho Solo.[12,23]

A mean SBS of 6.44 MPa for Greengloo and 7.69 MPa for Transbond Plus adhesive at 24 h was reported by Duers *et al*.[4] Lower amounts of SBS in their study compared to the present study may be attributed to the use of bovine teeth instead of human teeth, or the use of ground enamel surface instead of natural intact enamel surface. They used Transbond etching gel and Transbond primer for all the study groups and cured all the adhesives for 20 s. Ekhlassi *et al*.[5] used Transbond Plus self-etching primer and 20 s of light-curing time for all the groups and reported a mean SBS of 14.5 ± 2.8 MPa for Transbond Plus at 24 h, which is very close to the results of the present study (14.05 ± 4.24 MPa after 20 s of light-curing). On the contrary, they reported a mean SBS of 11.3 ± 2.8 MPa for Greengloo at 24 h, which is obviously different from 27.55 ± 3.47 MPa in the present study. This difference might be due to the different primers applied, i.e., Transbond Plus primer and Ortho Solo.

Conflicting results for the same adhesive type and curing time imply that other factors such as the type of primer may be responsible for differences in SBS. Scougall Vilchis *et al*.[20] reported that etch-and-rinse primer systems that use acid etchants provided higher surface roughness and subsequently higher SBS than self-etch primer systems. In the above-mentioned study, since all the groups had a SBS well above minimally acceptable level, the authors suggested the use of self-etching primers instead of etch-and-rinse systems as a step toward conservative treatment in an ideal clinical situation like perfect isolation and manipulation. Similarly, in the present study, the SBS with Transbond Plus adhesive which was used with a self-etch primer was significantly lower than that with Greengloo adhesive which was used with an etch-and-rinse primer system. However, the authors of an *in vitro* study concluded that the bond strengths obtained by self-etch and etch-and-rinse systems are not statistically different.[11]

Maintaining a sound and intact enamel surface is an important objective in orthodontic treatments. To this end, bond failures within the adhesive layer or at the bracket-adhesive interface are preferred to those at the enamel-adhesive interface. On the other hand, higher amounts of remnant adhesive need more chair time to remove.[5] Thus, there is a tradeoff between conservancy of orthodontic adhesives and convenience of the procedure for clinicians. CCAs are an impressive step forward toward faster and facilitated adhesive removal. In the present study, ARI scoring revealed that most of the debondings (88.8%) occurred in the adhesive layer. The ARI scores of Greengloo groups (III and IV) and Transbond plus groups (V and VI) did not exhibit a statistically significant difference; however, Transbond Plus groups showed significantly higher scores of ARI compared to the controls.

Mavropoulos *et al*.[3] in their study have reported that ARI scores were not significantly different with 20 and 40 s of light-curing times, consistent with the results of the present study. In their study as well as some others,[11,20] most of the debondings occurred at the bracket-adhesive interface or in the adhesive layer. In the present study, no bond failure occurred at the bracket-adhesive interface.

The majority of bond failures in Greengloo adhesive occurred within the adhesive layer, which is consistent with the results of a study by Türkkahraman *et al*.[12] Based on the results of the present study, regarding the highest amounts of SBS in Greengloo adhesive and the safe region of bond failure within the adhesive layer, this CCA may be a good candidate in cases where a high SBS is needed, such as rebonding of debonded brackets or bonding brackets to mutilated enamel.

In the present study as well as in the study by Türkkahraman *et al*.,[12] the majority of debondings at enamel-adhesive interface occurred with Transbond Plus adhesive, suggesting a potential risk of enamel damage with the use of this adhesive. However, the question is to what extent bond failures at enamel-adhesive interface contribute to enamel damage. Although, most of the debondings at enamel-adhesive interface (ARI score of 5) were observed with Transbond Plus adhesive, enamel fractures were predominantly observed in Greengloo adhesive (five out of six). However, due to the limited number of fractures for each adhesive, drawing a conclusion based on the current data is not feasible. Scougall Vilchis *et al*.[20] have reported, based on scanning electron microscope evaluation, that etch-and-rinse primer systems caused dramatic changes in the enamel surface due to enamel demineralization, resulting in higher bond strength. It was demonstrated that higher amounts of SBS lead to a higher frequency of enamel fracture,[20] consistent with the results of the present study. Therefore, the extent to which ARI scoring is predictive of enamel damage remains an important question. An ideal adhesive will show minimal amount of remnant adhesive and minimal change in enamel surface, while providing sufficient bond strength.

According to the limitations of this study, precise comparison between studies in the literatures requires matching of factors such as brand of light cure device, composites, their manufacturer propositions, power, intensity, area, wavelength of light, distance and etc. These factors are very important that should be considered in conjuction with the time. In addition, the findings of this study were obtained under *in vitro* conditions that may differ from intraoral conditions. Some factors such as enamel composition, saliva contamination and the difference between the universal testing machine forces and intraoral forces may affect the results in clinical situations.[5,10,12,24] Paucity of data indicates the demand for further clinical studies on the bond strength, risk of enamel damage, and measures to minimize this risk when color-change orthodontic adhesives are applied.

## CONCLUSION

Reducing the light-curing time from 40 to 20 s decreased the SBS in all the adhesives, and the difference between the SBSs of Transbond Plus groups was statistically significant; however, the mean SBSs of all the groups were still more than the safe limit. Among the two CCAs studied, Greengloo adhesive showed significantly higher SBS than Transbond Plus adhesive. ARI scores in Transbond Plus adhesive were significantly higher than the controls; however, ARI assessment did not yield significantly different results in Transbond Plus and Greengloo adhesives.

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