Original Article

Enhanced Degree of Monomer Conversion of Orthodontic Adhesives Using a Glass-Fiber Layer under the Bracket

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ABSTRACT

Objective: To test the hypothesis that there is no difference in the degree of conversion (DC%) of orthodontic composites during the light-curing process with or without the use of a glass-fiber reinforcement.

Materials and Methods: Two light-curing orthodontic adhesives, Transbond XT (TB) and Beauty Ortho Bond (BO), were used with woven preimpregnated glass fibers. The degree of monomer conversion was determined for both adhesives in three settings (n = 5 per group): in the first group, the adhesive was cured without a bracket (control); in the second group, the bracket was bonded using adhesive without fiber reinforcement; and in the third group, a layer of glass-fiber net was added between the bracket and resin. The adhesive resin was light cured, and the DC% was determined by Fourier transform infrared spectroscopy.

Results: A two-way analysis of variance revealed significant differences in the DC% ($P < .001$) between adhesives and between the fiber-reinforced and nonreinforced groups. When the nonreinforced adhesives were light cured under the brackets, the DC% was significantly lower (TB: 37.0%, SD 3.4; BO: 36.9%, SD 1.9) compared with the control (TB: 54.7%, SD 0.6; BO: 65.9%, SD 0.5). A higher DC% was found when the resin was light cured in the presence of a glass-fiber net (TB: 44.1%, SD 0.3; BO: 55.3%, SD 1.7).

Conclusion: The hypothesis is rejected. The degree of monomer conversion of the light-curing adhesive resin under stainless steel bracket can be improved by adding a thin layer of glass-fiber–reinforced composite between the bracket and adhesive resin. (*Angle Orthod.* 2009;79: 546–550.)

KEY WORDS: Fiber-reinforced composite; Orthodontic brackets; Degree of conversion; Bis-phenol A; Orthodontic adhesive

INTRODUCTION

Recently, a wide variety of light-cured orthodontic adhesives have become commercially available. Although many studies have investigated the bonding strength provided by various combinations of light-cured orthodontic adhesives with different light sources and times,[1–4] limited information has been presented with regard to the degree of conversion (DC%) of the resin material after light curing.[5–8] The DC% relates not only to the bond strength but also to other properties of the adhesive such as solubility and degradation.[7,9] Potential biological adverse reactions of the monomer have gained special interest in light of new evidence showing that resins may release Bis-phenol A, a Bis-GMA precursor that exhibits estrogenicity.[10] Ideally, a dental restorative or adhesive resin should have all of its monomer converted to polymer during polymerization. However, dimethacrylate monomers may exhibit considerable instauration in the final product, with the DC% ranging from 55% to 75% under conventional light irradiation.[11–13] Eliades et al[14] showed that there was a statistically significant linear correlation between the DC% of orthodontic adhesives and the residual Bis-GMA concentrations and that a

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Table 1. Materials Used in This Study[a]

Materials	Manufacturer	Lot No.	Code	Monomer Content
Transbond XT	3M Unitek (Monrovia, Calif)	6TF	TB	BisGMA, TEGDMA
Beauty Ortho Bond	Shofu (Kyoto, Japan)	12503	BO	BisGMA, TEGDMA

[a] BisGMA indicates bisphenol A-glycidyl dimethacrylate; TEGDMA, triethylene glycol dimethacrylate.

high concentration of residual Bis-GMA was found in the light-cured adhesive used to bond stainless steel brackets when the light-curing was performed through the bracket. Clinically, however, a considerable variation in the DC% is to be expected because of difficulties in irradiating the adhesive evenly from each side of the bracket.

Reinforcement of polymers with long, continuous fibers has been shown to have many clinical applications in dentistry. Fibers have been used in fixed prosthodontic appliances,[15] in endodontic posts and cores,[16] and in orthodontic retainers, space maintainers, and active appliances.[17–21] To be considered as viable alternatives to existing dental materials, the fiber-reinforced composites would need to offer clinically relevant applications that are easy to manipulate and customize.[22] The glass fibers impregnated with PMMA and Bis-GMA have been used as splinting units of tooth, repairing and reinforcing of veneers. In a recent study, Scribante et al[23] showed that a successful bond strength of orthodontic brackets can be obtained with a combination of resin and glass fiber. They recommend the use of Transbond XT adhesive system with a glass-fiber net when maximum bond strength is desired. Moreover, the ability of glass fibers to conduct and scatter light has been used in endodontically treated teeth.[24] This ability is a property that could be used to improve the DC% of adhesives when used with opaque structures such as stainless-steel brackets.

The aim of this study was to evaluate the effect of glass-fiber reinforcements on the DC% of two commonly used light-curing orthodontic adhesives under a stainless-steel bracket.

MATERIALS AND METHODS

Two orthodontic adhesives, Transbond XT (TB) and Beauty Ortho Bond (BO), were tested in the study (Table 1). In addition, 20 stainless-steel upper incisor brackets (Preci bracket, Lot No 050629, Shofu, Kyoto, Japan) were used. Glass-fiber nets with continuous bidirectional glass fibers (diameter Ø15 μm) were used in prepreg form (everStick NET, Stick Tech Ltd, Turku, Finland), containing a resin matrix of Bis-GMA and polymethylmethacrylate, which forms a resin matrix combined with cross-linked polymer material and thermoplastic phase, called a semi-interpenetrating polymer network for the glass fibers.[25]

Each of the two orthodontic adhesives were tested in a setting of three groups, with five specimens in each group. The DC% was monitored by Fourier transform infrared spectroscopy (FT-IR) (Spectrum One, Perkin Elmer, Beaconsfield Bucks, UK) with an attenuated total reflectance (ATR) sampling accessory.

In the first group (control), polymerization of the adhesive without a bracket was determined. A thin layer of adhesive was applied on the ATR (ZnSe-crystal, diameter Ø3.2 mm) and covered and pressed firmly by the microscope slides to ensure good contact of the specimen. The thickness of the adhesive was 100 μm. A handheld light-curing unit (light-emitting diode, Elipar Freelight 2, 3M ESPE AG, Seefeld, Germany) was applied right above the adhesive for 20 seconds. The light intensity was 920 mW/cm^2.

In the second group, polymerization of the adhesive under a stainless-steel bracket (3.3 × 4.3 mm) was determined. The bracket base was covered with adhesive and pressed firmly on the ATR. The excess resin was carefully removed before polymerization. Irradiation was performed from the medial and distal side of the bracket edges for 20 seconds on each side.

In the third group, a layer of glass-fiber net was added under the bracket and adhesive (Figure 1). Before polymerization, the glass-fiber net sheet was cut with scissors to the size of a central incisor bracket. A thin layer of adhesive was applied to cover completely the ATR. The glass-fiber net was bonded near the center on the facial surface of the adhesive layer with sufficient pressure to expel excess adhesive. Another layer of adhesive was applied to cover the fiber, and the bracket was pressed firmly on the ATR. The excess adhesive was carefully removed before polymerization. Irradiation was performed from the medial and distal side of the bracket edges for 20 seconds on each side.

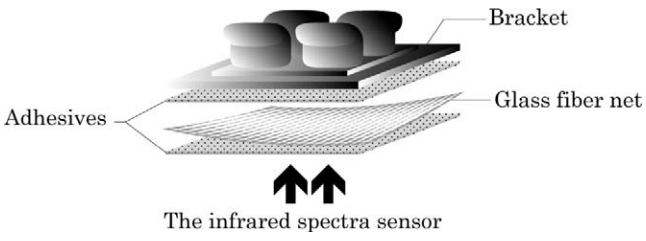

Figure 1. Schematic diagram of the adhesive layers with the glass-fiber net.

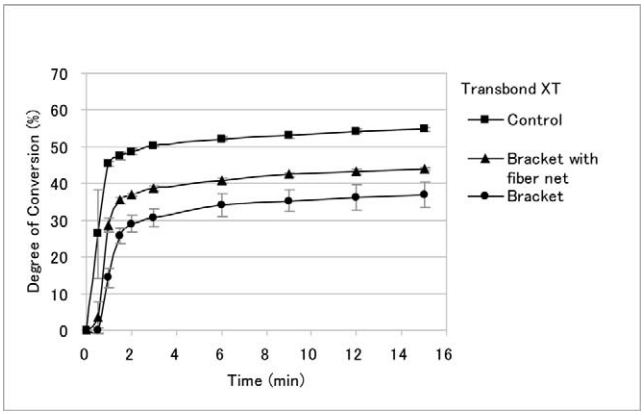

Figure 2. Mean degree of conversion (DC%) of Transbond XT with time from the start of polymerization in different conditions. Vertical lines represent 1 standard deviation.

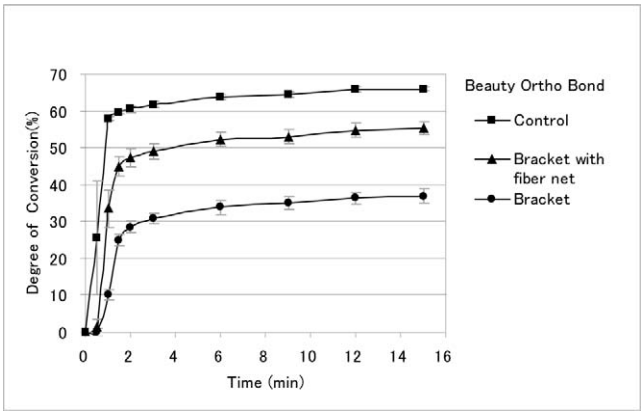

Figure 3. Mean degree of conversion (DC%) of Beauty Ortho Bond with time from the start of polymerization in different conditions. Vertical lines represent 1 standard deviation.

The infrared spectra from unpolymerized material and after light exposure at 0 min and then at 0.5, 1, 1.5, 3, 6, 9, 12, and 15 minutes was recorded using reaction kinetics software (TimeBaseV2, Perkin Elmer).

The DC% was calculated from the aliphatic C=C peak at 1638 cm^{-1} and was normalized against the aromatic C=C peak at 1608 cm^{-1} according to equation 1[26]:

$$DC\% = \left(1 - \frac{C_{aliphatic}/C_{aromatic}}{U_{aliphatic}/U_{aromatic}}\right) \cdot 100\% \qquad (1)$$

where

$C_{aliphatic}$ = absorption peak at 1638 cm^{-1} of the cured specimen
$C_{aromatic}$ = absorption peak at 1608 cm^{-1} of the cured specimen
$U_{aliphatic}$ = absorption peak at 1638 cm^{-1} of the uncured specimen
$U_{aromatic}$ = absorption peak at 1608 cm^{-1} of the uncured specimen

The fraction of the remaining double bonds for each spectrum was determined by standard baseline techniques using the comparison of maximum heights of aliphatic and reference peaks for calculations.

Data from the DC% were analyzed with a two-way analysis of variance (ANOVA) using the adhesive material and group as independent variables. Furthermore, Tukey's multiple comparisons post hoc analysis was employed at a significance level of $P < .05$.

RESULTS

The changes of DC% of TB and BO in the three test groups plotted against time are shown in Figures 2 and 3, respectively. At the beginning of light-cure radiation, the DC% showed a sharp increase in all groups. The increase was faster in group 3 (bracket plus glass-fiber net) than in group 2 (bracket only).

The mean DC% values and standard deviations obtained at 15 minutes after polymerization are shown in Table 2. At this point, BO and TB cured directly without brackets (controls) showed DC% values of 65.9% (SD 0.5%) and 54.7% (SD 0.6%), respectively. In group 2, in which the resin under a steel bracket was light cured for 20 seconds on each side of the bracket, the tested adhesives showed DC% values that were 32.4% (TB) and 43.9% (BO) lower than their respective controls. In group 3, in which a glass-fiber net had been added, the DC% value of TB was increased up to 44.1 DC% (SD 0.3%), and BO was increased even more significantly up to 55.3 DC% (SD 1.7%).

An ANOVA showed significant differences in DC% according to the following factors: different materials (TB vs BO, $P < .001$) and different conditions (fiber-reinforced vs nonreinforced, $P < .001$). There were some interactions between the factors ($P < .05$).

DISCUSSION

Among several methods to determine the DC% of orthodontic adhesives, FT-IR has been proven to be

Table 2. Degree of Conversion (DC%) of Different Adhesives and Conditions in This Study (n = 5), 15 Minutes After Polymerization

Adhesive	Condition	DC%	SD	Tukey Grouping[a]
Transbond XT	Control	54.7	0.6	C
	Bracket	37.0	3.4	A
	Bracket with fiber net	44.1	0.3	B
Beauty Ortho Bond	Control	65.9	0.5	D
	Bracket	36.9	1.9	A
	Bracket with fiber net	55.3	1.7	C

[a] Means with the same letters are not significantly different at the $P < .05$ level.

a powerful technique and has been widely used as a reliable method,[5–9,11,14] based on the determination of the C=C stretching vibrations directly before and after curing of materials. However, the method has some limitations. For example, the method does not allow assessment of the depth of cure; that is, it tends to ignore possible differences in the level of polymerization between the top and bottom layers of the specimen. Therefore, the DC% values reported in this study are averages from the bottom layers of the adhesive.

Polymerization of the adhesive under an opaque stainless-steel bracket depends on the ability of the light to penetrate the resin material and on the amount of light scattered from the background surface.[27] The present results showed that the DC% in the adhesive layer under the bracket is low, where light is not able to penetrate. The DC% values of 36.9% to 37.0% found in the present study indicate that high monomer leaching can occur from the adhesives.[14] However, the addition of a glass-fiber net in the adhesive under the bracket increased the level of DC% for the tested adhesives. The results suggest that by using a glass-fiber net with the adhesive resin, the DC% can be increased to a more acceptable level. This might be due to the fiber's ability to conduct light. Furthermore, the final DC% varied less among the specimens that had a glass-fiber net (Table 2), suggesting that the light curing of the resin can be carried out in a more consistent manner in the presence of glass fibers. Even though there are some interactions between the factors in this study, the general behavior of the two cements was similar. The mean DC% values of BO cured directly without the bracket (control) were higher than that of the TB controls. Moreover, the DC% of BO under the bracket showed the lowest values of all the groups. It is probable that these results caused some of the interactions.

Another interesting observation was that the DC% of the adhesives at the beginning of the curing process progressed faster with a glass-fiber net than without it. This finding supports the typical behavior of polymerization of acrylates: that an increased reaction rate will end up with a higher DC%. Although standards for acceptable levels of DC% of adhesives are lacking, the use of a glass-fiber net can be recommended as an efficient method to improve the level of DC% of orthodontic adhesives under steel brackets.

Adhesive layers under the bracket forms varied in thickness with a range of approximately 90 μm depending on the bracket base structure.[7,28] The thickness of the glass-fiber net used in this study is only 60 μm, and it has only a minor effect on the thickness of the adhesive layer. However, further research is required to verify whether the thickness of the adhesive under the bracket is concerned with DC%.

CONCLUSIONS

- When bonding steel brackets with light-cured orthodontic adhesives, a rather low DC% results.
- The DC% can be enhanced by inserting a glass-fiber net between the bracket and adhesive.

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