Conventional and High-Intensity Halogen Light Effects on Polymerization Shrinkage of Orthodontic Adhesives

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ABSTRACT

The objectives of this study were to compare the polymerization shrinkage of three orthodontic adhesives. In addition we wanted to determine the effectiveness of the high-intensity quartz tungsten halogen (HQTH) in curing orthodontic adhesives on polymerization shrinkage with that of the quartz tungsten halogen (QTH). A total of 120 glass ring molds were prepared using a low-speed saw. The internal surface of the glass rings were roughened and etched. Adhesive pastes were placed into the glass molds, which were sandwiched between two glass slides. Samples were divided into six groups according to the combination of three orthodontic adhesives (Kurasper F, Light Bond, and Transbond XT) and two light intensities. One half of each 40 samples of three adhesive pastes was polymerized for 20 seconds by a QTH (Hilux 350), and the other half was polymerized for 10 seconds by a HQTH (Optilux 501). The volumetric polymerization shrinkage for each system was measured through the specific density method modified by Puckett and Smith. Statistical analysis was performed using two-way analysis of variance for intergroup comparisons. The HQTH-curing unit resulted in a more polymerization shrinkage than did the QTH for all investigated adhesives. However, no statistically significant differences were found. The highest shrinkage was observed for Light Bond cured with HQTH (1.59 $\pm$ 0.82%), and the lowest value was observed for Transbond XT cured with QTH (1.23 $\pm$ 0.60%). There are no significant differences in polymerization shrinkage of the three investigated orthodontic adhesives when polymerized with a QTH or a HQTH.

KEY WORDS: Polymerization shrinkage; Quartz halogen; Light intensity

INTRODUCTION

A wide variety of visible light-cured orthodontic adhesives has become commercially available in orthodontic field. The high early bond strength,[1] minimal extent of oxygen inhibition,[2] and the extended working time for optimal bracket placement are the advantages of visible light-cured orthodontic adhesives. The major disadvantage of these adhesives is the fact that they shrink during polymerization, causing shrinkage strain and marginal gaps at the tooth-adhesive interface.[3] Therefore, the reduction of polymerization shrinkage presents an important goal in biomaterials research.

The best activation method of the orthodontic composite is probably the one that promotes as little polymerization shrinkage as possible. This will result in the lowest shrinkage stress value, which will, in turn, least affect the integrity of the tooth and the mechanical bonding of the material.[4]

Feilzer et al[5] reported that the polymerization contraction stress increased with the increase of configuration factor (C-factor), which was defined by the ratio of bonded surfaces to unbonded surfaces. Because the C-factor can be very high in the case of orthodontic bracket bonding, the polymerization shrinkage may influence significantly the durability of the bracket bond.

The use of high-intensity units has been recommended almost universally[6] because they would be able to enhance monomer conversion. Polymerization

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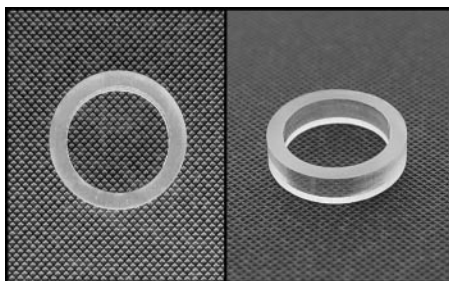(e-mail: tancanuysal@yahoo.com)

FIGURE 1. Glass ring molds.

FIGURE 2. Low-speed saw.

by a high-intensity quartz tungsten halogen (HQTH)–curing unit occurs rapidly. Conversely, some authors do not indicate the use of high-intensity light units based on the fact that this type of unit induces higher polymerization shrinkage and larger residual stress in dental filling composites.[7,8] In recent years, many different methods have been studied aiming to reduce the effects of polymerization shrinkage, ie, use the different light-activation techniques such as pulse delay,[9] soft-start cure, and pulse cure,[9] development of resins that do not shrink when they polymerize[10] or that expand through a double-ring open process,[11] and the use of the incremental filling technique.[12,13] However, in the orthodontic literature, few studies exist concerning the differences in polymerization shrinkage of orthodontic adhesive resins irradiated using conventional and high-intensity halogen-curing systems.

The purposes of this study were to compare the volumetric polymerization shrinkage values of three adhesive resins used in orthodontic practice. In addition

we planned to determine the effectiveness of the HQTH light on polymerization shrinkage with that of the quartz tungsten halogen (QTH) light. The hypothesis proposed in this study was that when the equivalent total light energy was irradiated to the three orthodontic adhesive resins, the polymerization shrinkage would be the same regardless of curing light sources (QTH and HQTH).

MATERIALS AND METHODS

A total of 120 glass ring molds (8.5 mm in inner diameter and 2 mm in height) were prepared (Figure 1) using a low-speed saw (Isomet, Buehler Ltd., Ill) (Figure 2). The internal surface of the glass rings were roughened and etched for 5 minutes with hydrofluoric acid (Etch-It, American Dental Supply, Easton, Pa). The glass molds were then weighed in air and in water with an electronic balance (Shimadzu AY220, Shimadzu Corp., Kyoto, Japan) to calculate their density and volume.

Three different commercially available orthodontic adhesive pastes, Kurasper F (Kuraray, Okayama, Japan), Light Bond (Reliance, Itasca, Ill), and Transbond XT (3M Unitek, Monrovia, Calif), were used in this study (Table 1). A total of 40 samples for each adhesive paste were placed into the glass molds, which were sandwiched between two glass slides. To ensure that the adhesive paste would be well distributed within the mold, five N was applied for 30 seconds. The samples were stored in dark and dry conditions at 37°C for 24 hours after light curing, before they were weighed both in air and in water to calculate their density and volume.

One half of each of the 40 samples of three adhesive pastes was polymerized for 20 seconds by a QTH light source (Hilux 350, Express Dental Products, Toronto, Canada) with a 10-mm-diameter light tip. The other half was polymerized for 10 seconds by a HQTH light source (Optilux 501, Kerr, Danbury, Conn) with a 10-mm-diameter light tip. Regarding the curing units, the important parameter is the amount of light energy of appropriate wavelength emitted during irradiation. This energy is calculated as the product of the output of the curing unit and the time of irradiation, and it may be termed energy density (J cm^{-2}). The outputs of the

TABLE 1. Orthodontic Adhesive Resins Used in This Study

Adhesive Code	Brand Name	Composition	Batch Number	Manufacturer
KF	Kurasper F	Bis-GMA, TEGDMA, HEMA, NaF and MF-MMA copolymer containing fluorine, silica filler.	41123	Kuraray, Okayama, Japan
LB	Light Bond	UDMA, TEGDMA, fused silica, sodium fluoride	104160	Reliance Itasca, Ill
TX	Transbond XT	Bis-GMA, Bis-EMA, TEGDMA, silanated quartz, submicron silica	200401	3M Unitek Monrovia, Calif

light tips were calibrated by a digital curing radiometer (Demetron, Danburry, Conn) as 420 mW/cm^{-2} for Hilux 350 and as 850 mW/cm^{-2} for Optilux 501. At the start of irradiation, these outputs were measured as 430 and 865 mW/cm^{-2} for Hilux 350 and Optilux 501, respectively. However, the light intensity decreased 17.2 mW/cm^{-2} for Hilux 350 and 24.7 mW/cm^{-2} for Optilux 501, with usage. The total light energy was calculated with the mean output values about:

QTH: 420 mW/cm^{-2} × 20 seconds = 8400 mJ cm^{-2}
HQTH: 850 mW/cm^{-2} × 10 seconds = 8500 mJ cm^{-2}

Volumetric shrinkage calculation—the volumetric polymerization shrinkage for each system (n = 20)—was measured through the specific density method modified by Puckett and Smith[14] using the following relationships:

$$V_0 = (\pi D^2 h)/4$$
$$V_1 = 10^3 (W_0 - W_1) \rho_T$$
$$V_2 = 10^3 (W_2 - W_3) \rho_T$$
$$V_3 = V_2 - V_1$$
$$\Delta V = V_0 - V_3$$

% shrinkage = $10^2 (\Delta V/V_0)$, where

V_0 = volume of glass ring cylindrical hole (mm^3)
D = inner diameter of glass ring (mm)
h = glass ring height (mm)
V_1 = volume of glass ring (mm^3)
W_0 = weight of glass ring in air (g)
W_1 = weight of glass ring in water (g)
ρ_T = density of water at temperature T (°C) (g/mm^3)
V_2 = volume of glass ring + composite sample (mm^3)
W_2 = weight of ring + composite sample in air (g)
V_3 = volume of adhesive paste sample after polymerization (mm^3)
W_3 = weight of ring + composite sample in water (g)
ΔV = volumetric shrinkage (mm^3)

The C-factor (C) of all specimens was calculated as follows[5]:

C = (total bonded area)/(total unbonded area)
   = 2h/D,

where

h = height of glass ring (mm)
D = diameter of glass ring (mm)

Samples were divided into six groups according to the combination of two light intensities and three orthodontic adhesives. The results of testing were entered into an Excel (Microsoft, Seattle, Wash) spreadsheet for calculation of descriptive statistics.

For all groups, the average values and standard deviations were calculated. Statistical analysis was performed using two-way analysis of variance (ANOVA) (subsequent to confirmation of normal distribution and homogeneity of variance) (Statistical Package for Social Sciences, SPSS Ver.10.0, SPSS, Chicago, Ill) for intergroup comparisons (each adhesive and each curing unit) at the 0.05 level of significance.

TABLE 2. The Polymerization Shrinkage Mean Values and Standard Deviations of Three Orthodontic Adhesive Resins Cured With QTH and HQTH[a,b]

		QTH		HQTH		
		Mean	SD	Mean	SD	*P*
Group A	Kurasper F	1.28	0.56	1.41	0.38	NS
Group B	Light Bond	1.43	0.68	1.59	0.82	NS
Group C	Transbond XT	1.23	0.6	1.37	0.61	NS

[a] QTH indicates quartz tungsten halogen; HQTH, high-intensity quartz tungsten halogen; and NS, not significant.
[b] Polymerization shrinkage (%) (n = 120). For each of the groups, group A, group B, and group C, n = 40.

RESULTS

When the glass ring was filled with orthodontic adhesive and polymerized, the adhesive was bonded to the etched internal surface of the glass ring to produce a mold with a C-factor of approximately 0.5.

The polymerization shrinkage mean values and standard deviations of three orthodontic adhesive resins cured with QTH and HQTH are separately shown in Table 2. For all adhesives, the HQTH light–curing unit resulted in more polymerization shrinkage than did the QTH. There are notable increases in polymerization shrinkage when the specimens were irradiated using the HQTH, but there were no statistically significant differences in polymerization shrinkage among three orthodontic adhesives tested. The highest polymerization shrinkage was observed for Light Bond cured with HQTH (1.59 ± 0.82%), and the lowest value was observed for Transbond XT cured with QTH (1.23 ± 0.60%).

According to the two-way ANOVA, polymerization shrinkage of the three orthodontic adhesive resins did not vary significantly between the different curing units used ($P > .05$). The null hypothesis was thus accepted. Two-way ANOVA revealed no significant interaction among the curing unit type and orthodontic adhesives ($P > .05$).

DISCUSSION

Polymerization shrinkage may create contraction stresses in the composite material, which can disrupt

the marginal seal between the composite and the tooth structure. In the case of orthodontic bracket bonding, the polymerization shrinkage may influence significantly the durability of the bracket bond.[15]

The most widely used light sources for photo activating resin-based materials are conventional QTH light units.[15] On the other hand, modern fast-curing units such as lasers, plasma-arc lights, light-emitting diodes (LED), and HQTH have been developed to reduce curing time.[6,16] A conventional light-curing unit with a halogen lamp requires 30–50 seconds per bracket to cure orthodontic adhesive resin. Under these conditions, the irradiation time for bonding both maxillary and mandibular arches can reach up to 10–15 minutes, and the long irradiation time may be a great drawback for both clinician and patient. The high-intensity curing units make the light appropriate for the rapid curing of resins, including those used as orthodontic adhesives.[15]

The HQTH light is capable of producing light of a greater intensity than that of the QTH light and may be sufficient for the fast curing of adhesives, including those used for orthodontic bonding purposes. Nomoto et al[17] found that when the comparable total light energy was irradiated to the resin, the curing depth and the degree of conversion might be the similar regardless of the differences in the light intensity or irradiation time. In addition, higher light intensity could result in increased fracture, hardiness, and greater flexural strength of resin, which would translate into greater bond strength of brackets bonded to teeth.[18] However, the probable negative effect of the HQTH lights must also consider the polymerization process. Some authors[7,8] reported that the use of HQTH lights may cause a rapid development of polymerization stresses and the shrinkage of adhesive resins may lead to destructive contraction stresses in orthodontic brackets. With these advantages and disadvantages in mind, this in vitro study was performed to investigate the effects of QTH and HQTH light sources on polymerization shrinkage of three orthodontic adhesives.

The preparation designs have some effects on the stress generated during resin polymerization. The ratio of the bonded to unbonded surfaces, the C-factor, within the preparation can be calculated to predict which adhesives are most likely to exhibit bond failures between the adhesive and the tooth.[5] In this study, the C-factor values for all specimens were calculated, and the average value was found to be approximately 0.5. The experimental design with a C-factor of approximately 0.5 was found suitable because in a C-factor of above 1, the bond between the mold and the resin may fail.[5]

Although polymerization shrinkage is dependent on time, most of the shrinkage occurs in the first 10 min-utes, and it was found that little change had occurred after 1 hour.[19,20] The volumetric shrinkage was measured at least 1 hour after light curing, and therefore, the 1–24 hour time interval in which the specimens were tested was not considered to have influenced the results.

Bang et al[15] investigated the polymerization shrinkage of three commercial orthodontic adhesive resins (Enlight, Transbond XT, and Light Bond) and found statistically significant differences among them. They reported that the adhesive resin with the highest filler fraction—Light Bond—showed the highest polymerization shrinkage cured with two different units (QTH and plasma arc). However, inorganic fillers are added to reduce polymerization shrinkage and water sorption, to increase strength, and also to impart color characterization to the material.[21] In this study, there were no statistically significant differences on polymerization shrinkage of all investigated orthodontic adhesive resins. However, Light Bond showed the highest and Transbond XT showed the lowest polymerization shrinkage values when cured with both QTH and HQTH. These differences might be explained by the variation in the chemical components and filler compositions of these orthodontic adhesive resins.

In the literature, there are many more studies in restorative dentistry investigating the relationships between curing light type and polymerization shrinkage. Feilzer et al[7] showed that the use of high-intensity curing light units negatively affected the integrity of the restoration cavity interface in Class V restorations. Hofmann et al[22] indicated that shrinkage strain was greater after QTH irradiation compared with both LED units (Herculite, Definite) or with the weaker LED light (Z250). Bang et al[15] irradiated equivalent total light energy with conventional halogen and plasma-arc unit on orthodontic adhesives and found statistically significant differences in polymerization characteristics. They found that the polymerization shrinkage of orthodontic adhesives cured with the plasma-arc unit was significantly lower than that with QTH light unit and they proposed several factors (ie, lower thermal effects and rapid increase in viscosity of the adhesives cured with the plasma-arc unit could give rise to lower polymerization shrinkage) to explain the differences in the curing effectiveness. Present findings indicate that, when the equivalent total light energy was irradiated, all three orthodontic adhesive resins cured with the HQTH light resulted in a more polymerization shrinkage than did the QTH light. However, there was no statistically significant difference in polymerization shrinkage between the curing units tested.

Further studies are necessary to investigate the effective usage, capability, and limitations of HQTH light sources.

CONCLUSIONS

- No statistically significant differences were found among three investigated orthodontic adhesive resins.
- Polymerization shrinkage of the orthodontic adhesive resins did not vary significantly between the different curing units (QTH light and HQTH light).
- Two-way ANOVA revealed no significant interaction among the curing unit type and orthodontic adhesives.
- HQTH light units seem to be useful because of the reduced curing time and similar polymerization shrinkage with QTH when polymerizing light-activated orthodontic adhesives. However, polymerization shrinkage is not the only factor related with the success of a light source.

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