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Correlation Between the Amount of Linear Polymerization Shrinkage and Cuspal Deflection

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Clinical Relevance

When restoring teeth with Class II cavities, the amount of polymerization shrinkage value of composites determines the amount of cuspal deflection of teeth. Thus, resin composites with low polymerization shrinkage should be used to reduce cuspal deflection.

SUMMARY

This study evaluated the relationship between the amount of cuspal deflection and linear polymerization shrinkage in resin composites and polyacid modified resin composites (compomers). Materials included were Dyract AP, Compoglass F, Z100, SureFil, Pyramid, Synergy Compact, Heliomolar and Heliomolar HB. To measure polymerization shrinkage, a custom-made linometer (R&B, Daejon) was used. Ten measurements were made for each group, and the amount of linear shrinkage that occurred in 60 seconds was statistically compared by one-way ANOVA analysis and Tukey's test. To measure the cuspal deflection of teeth, standardized MOD cavities were prepared in extracted maxillary premolars. After a self-etching adhesive was applied, the cavities were bulk filled with one of the filling materials. Fifteen teeth were used for each material. Cuspal deflection was measured by a custom-made cuspal-deflection measuring device. One-way ANOVA analysis and Tukey's test were used to determine differences between the materials. The correlation of polymerization shrinkage vs cuspal deflection was analyzed by regression analysis.

The amount of polymerization shrinkage from least to greatest was Heliomolar, SureFil < Heliomolar HB < Z100, Synergy Compact < Dyract AP < Pyramid, Compoglass F (p<0.05).

The amount of cuspal deflection from least to greatest was Z100, Heliomolar, Heliomolar HB, Synergy Compact, SureFil, < Compoglass F < Pyramid, Dyract AP (p<0.05).

Both the amount of polymerization shrinkage and cuspal deflection were highly correlated (p<0.001).

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INTRODUCTION

Dental resin composite shrinks by 1-5 vol% during polymerization (de Gee, Davidson & Smith, 1981). Due to polymerization shrinkage, clinical problems such as postoperative sensitivity, secondary caries and cracks can occur (Eick & Welch, 1986; Kemp-Scholte & Davidson, 1988; Soderholm, 1991). In addition, microcracks in the composite body can occur, which lead to higher wear of the composite (Roberts, Powers & Craig, 1977). Even though polymerization shrinkage is currently unavoidable, the clinical effects of shrinkage can be minimized by controlling the configuration factor (C-factor) (Feilzer, de Gee & Davidson, 1987) by using a liner (Kemp-Scholte & Davidson, 1990; Lutz, Krejci & Oldenburg, 1986) and by modulation of the curing initiation (Uno & Asmussen, 1991; Ernst & others, 2000).

It has been reported that placing composites in Class II cavities leads to inward deformation of the cusps, and the amount of this deformation has been observed to vary from 15 to 50 µm (Causton, Miller & Sefton, 1985; Pearson & Hegarty, 1987; Lutz, Krejci & Barbakow, 1991). Such deformation can lead to fracture of the enamel or tooth and postoperative sensitivity (Eick & Welch, 1986; Kemp-Scholte & Davidson, 1988; Soderholm, 1991). Even though the inwardly deformed cusps tend to return to their original position with time, recovery to the original dimension in large cavities does not occur (Suliman, Boyers & Lakes, 1993).

Manufacturers have added more inorganic filler particles in composites to reduce polymerization shrinkage. This also increases strength and stiffness (E-modulus) of the composite materials but, unfortunately, increases in modulus are associated with higher polymerization shrinkage stresses. The use of low modulus restoration or the application of a flexible adhesive lining has been shown to render the release of polymerization shrinkage stress and thus has been recommended as a tool to increase marginal adaptation (Kemp-Scholte & Davidson, 1990; Davidson & Abdalla, 1993). Whereas, the effects of polymerization shrinkage stress on marginal adaptation seem to be evident, the effects on cuspal deflection are not evident. Ausiello and others (2001) reported in their Finite Element Model (FEM) study that cuspal deflection was higher with more rigid composites, but that recovery of the initial distance was lesser with flexible composites. Lee and Park (2004) reported that there was no correlation between polymerization shrinkage stress and the cuspal deflection of teeth. They speculated that even flexible composites could lead to greater cuspal movement compared to rigid composites if the amount of polymerization shrinkage of flexible composites exceeded that of the rigid composite. Therefore, it is important to study the relationship between the amount of polymerization shrinkage and cuspal deflection to obtain further information.

In composites, it has been acknowledged that increasing filler content reduces the amount of polymerization shrinkage and increases the modulus of elasticity. However, higher filler loads usually require low molecular weight monomers to ensure the proper handling of viscosity in commercial composites. In most cases, low molecular weight monomers increase the amount of polymerization shrinkage and decrease the modulus of elasticity. Thus, the relationship between filler content and the amount of polymerization shrinkage may not be simple and would be meaningful to evaluate.

This study evaluated the relationship between the amount of polymerization shrinkage and cuspal deflection. A null hypothesis was that there was no correlation between them. Additionally, the relationship between the amount of polymerization shrinkage and filler content was evaluated.

METHODS AND MATERIALS

A. Linear Shrinkage Measurement

Six brands of light cured composites and two brands of polyacid modified resin composite (compomer) were used (Table 1). The materials, which were pressed out of the syringe, were transferred to a Teflon mold to ensure that the same amount of composite and compomer was used for each linometer sample. Then, the materials were transferred to the disk in the custom-made linometer (R &B, Daejeon, Korea) that had been previously coated with a separating glycerin gel and then covered with a glass slide and loaded under constant pressure. The surface of the glass slide facing the specimen was also coated with the separating gel. The specimens were light cured with a quartz tungsten halogen curing unit (XL3000, 3M Dental Product, St Paul, MN, USA), with a power density of 730mW/cm^2 when measured with a Coltolux Light Meter (Coltene, Altstätten, Switzerland). The tip of the curing light was positioned 2 mm above the glass slide to ensure proper curing of the specimens, then light cured for 60 seconds. As the composite under the slide glass was cured, it shrank towards the light source, and the aluminum disk under the composite moved upward. The amount of disk displacement, which was caused by linear shrinkage of the resin composite, was measured using an eddy current sensor every 0.5 seconds for 60 seconds. The precision eddy current non-contact measuring system is based on electromagnetic induction and

Table 1: *Restorative Materials Used in This Study*

	Manufacturer	Lot #
Z100	3M Dental Products, St Paul, MN, USA	20010925
Pyramid	BISCO Inc, Schaumburg, IL, USA	0100014949
Dyract AP	Dentsply DeTrey GumbH, Germany	0207000629
Heliomolar	Ivoclar Vivadent, Schaan, Liechtenstein	E54834
Heliomolar HB	Ivoclar Vivadent, Schaan, Liechtenstein	E00067
Synergy Compact	Coltene, Altstätten, Switzerland	LH725
SureFil	Dentsply Caulk, Milford, DE, USA	011211
Compoglass F	Ivoclar Vivadent, Schaan, Liechtenstein	D51379

is one of the methods that measures the distance from the target to the sensor. Park, Krejci and Lutz (1999, 2002) previously reported the design of the linometer. Ten measurements were made for each group, and the amount of linear shrinkage occurring in 60 seconds was statistically compared by one-way ANOVA and Tukey's test as a post hoc test at the 95% confidence level.

B. Cuspal Deflection Measurement

Upper premolars recently extracted for orthodontic reasons were used. During the extraction process, the teeth were sufficiently loosened with an elevator, and special care was taken in the use of forceps so as not to cause any damage to the teeth. The teeth were examined with a magnifier, and those with no cracks, caries or any other defects were selected. Special care was also taken to control the tooth shape and size, bucco-lingual diameter and crown height. Modified MOD cavities were prepared 3-mm deep and 3.5-mm wide (Figure 1). After cleansing the cavity and tooth with fluoride-free pumice, a self-etching primer system (SE-bond, Kuraray, Okayama, Japan) was applied according to the manufacturer's instructions. Using the Teflon mold, the same volume of composite or polyacid modified resin composite (Table 1) was measured and transferred to the cavities and bulk filled. Before and after the cavities were filled, the weight of the tooth specimens was also measured. These procedures took about 50-60 seconds and were carried out in a custom-made box in which the 400-500 nm wavelength light was shut off to prevent light polymerization of the restorative materials.

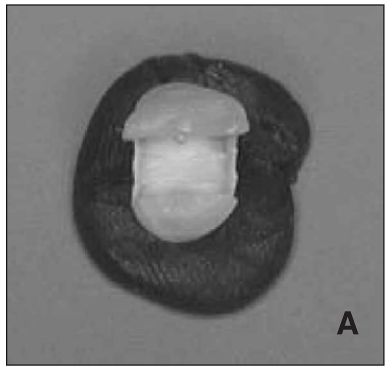

Figure 1. *Cavity preparation. Upper view (a) enamel.*

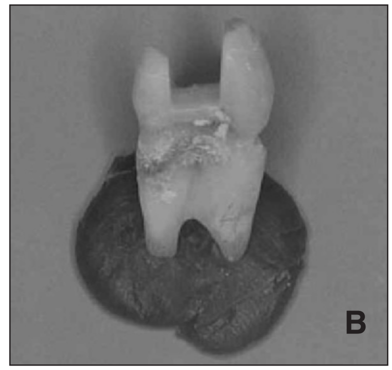

Figure 1. Cavity preparation Side view (b).

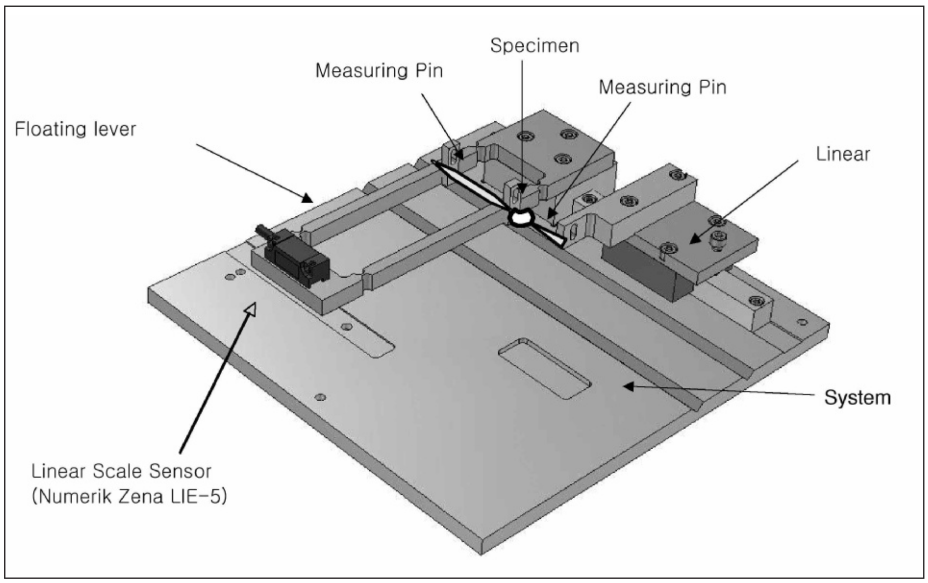

Figure 2: *Schematic drawing of cuspal deflection measuring machine.*

The specimens were positioned in the custom-made cuspal deflection measuring system (R & B) using the screw and pin. The point where the pin was positioned on the tooth surface was controlled through the specimens. When the specimens were positioned using the screw on one cusp tip, the pin, which was positioned in the other cusp tip, was pushed back. When the specimen was positioned, the intercuspal distance was set at point zero. The specimens were light cured from the occlusal, mesial and distal surface for 60 seconds, each with a quartz tungsten halogen curing unit (XL3000, 3M Dental Products) with a power density of 730mW/cm^2 when measured with a Coltolux Light Meter (Coltene). The inward cuspal movement changed the position of the pin and floating lever, and it was detected by a Linear scale sensor (Lie5, Numerik Jena Gmbh, Jena, Germany) (Figure 2). Data were stored in the computer simultaneously for 10 minutes. Fifteen specimens were used for each material. The amount of cusp movement was compared among the materials by one-way ANOVA and Tukey's test at the 95% confidence level.

C. Correlation Between Amount of Linear Shrinkage and Cuspal Deflection

Using the data in experiments A and B, a regression analysis was performed between the amount of cuspal deflection and linear shrinkage.

RESULTS

1. Measurement of Linear Polymerization Shrinkage

The amount of linear polymerization shrinkage is summarized in Table 2. The amount of linear polymerization shrinkage from least to greatest is SureFil, Heliomolar<Heliomolar HB< Synergy compact, Z100<Dyract AP< Pyramid, CompoglassF (p<0.05), and shrinkage ranged from 8.6 ± 4 µm to 10.9 ± 1 µm.

The pattern of linear polymerization shrinkage for the materials is shown in Figure 3. In all groups, the slope of curve is steep in the first 20 seconds and, thereafter, it becomes more gradual.

2. Measurement of Cuspal Deflection

The amount of cuspal deflection is summarized in Table 3. The amount of cuspal deflection in ascending order is Z100, Heliomolar, Heliomolar HB, Synergy Compact, SureFil < Compoglass F < Pyramid, Dyract (p<0.05) and ranged from 14.63 ± 2.32 µm to 22.75 ± 3.36 µm.

The degree of cuspal deflection versus time is shown in Figure 4. In all groups, the slope of curve is steep in the first 300 seconds and, thereafter, that it becomes more gradual. In all groups, there is a slight jump in slope at 180 seconds.

3. Correlation Between Polymerization Shrinkage Amount Versus Cuspal Deflection

The amount of the polymerization shrinkage and cuspal deflection were highly correlated (p<0.001, Pearson Correlation Constant 0.54076) (Figure 5).

DISCUSSION

The results of this study indicate that the amount of polymerization shrinkage and cuspal deflection are highly correlated. The materials that showed a lower shrinkage value also demonstrated lower cuspal deflection. As cuspal deflection increases, the chances of crack formation in a tooth would also increase and may also cause clinical symptoms such as temperature sensitivity and pain upon biting (Eick & Welch, 1986; Kemp-Scholte & Davidson, 1988; Soderholm, 1991). Therefore, in large Class II cavities, resin composite with a low polymerization shrinkage value should be used to reduce cuspal deflection.

Lee and Park (2004) indicated that there was no correlation between the amount of polymerization shrinkage stress and cuspal deflection. Even though one material has a low shrinkage value, it may have high shrinkage stress, depending on the modulus of elasticity of the material (Park & others, 2003). Ferracane and Mitchem (2003) reported that leak-

Table 2: *Amount of Linear Shrinkage and Standard Deviation (µm)*

Z100	8.57 ± 0.38
Pyramid	10.36 ± 0.98
Dyract AP	9.74 ± 0.38
Heliomolar	6.91 ± 0.78
Synergy Compact	8.46 ± 0.66
Compoglass F	10.93 ± 0.96
SureFil	6.67 ± 0.28
Heliomolar HB	8.06 ± 0.56

Table 3: *Mean Value of Cuspal Deflection and Standard Deviation (µm)*

Z100	14.63 ± 2.32
Pyramid	22.73 ± 2.12
Dyract AP	22.75 ± 3.36
Heliomolar	15.30 ± 1.97
Synergy Compact	16.01 ± 1.16
Compoglass F	19.42 ± 2.92
SureFil	17.02 ± 2.86
Heliomolar HB	15.79 ± 1.73

Table 4: *Filler Contents of Posterior Composites*

Composite	% of filler[a]
Z100	66 vol%
Pyramid	80 wt%
Dyract AP	73 wt%
Heliomolar	66.7 wt%
Heliomolar HB	66.7 wt%
Synergy Compact	74 wt%
SureFil	60-68 wt%
Compoglass F	79 wt%

[a]: *obtained from manufacturers' technical manual and home page.*

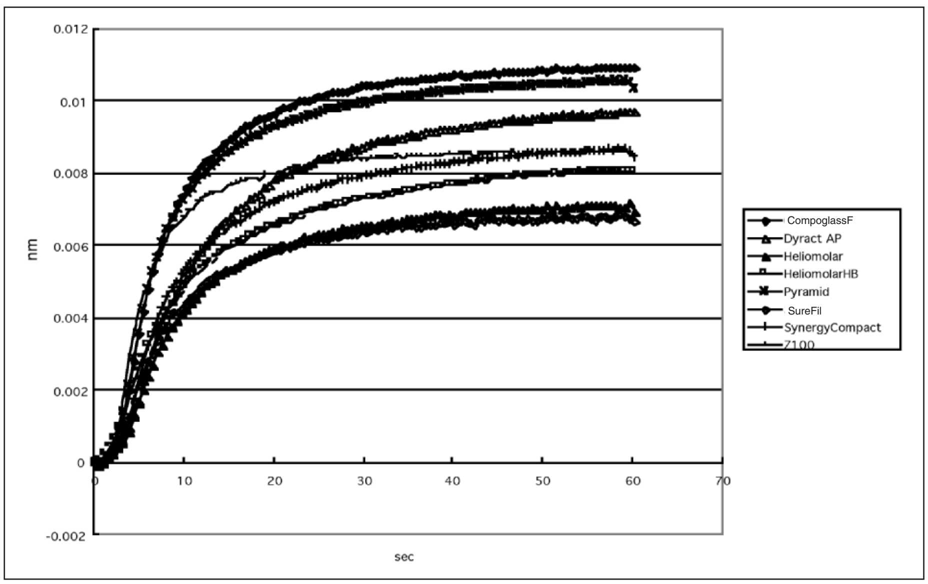

Figure 3: *Linear polymerization shrinkage versus time.*

age results correlated with stress values; that is, composites with higher contraction stress showed more extensive marginal leakage; whereas, Lutz and others (1991) reported that both quality and stress resistance of marginal adaptation were inversely correlated to intercuspal narrowing caused by polymerization contraction of bonded and a well adapted resin restoration. According to Lutz and others, the most effective factors that can optimize marginal quality include guidance of shrinkage vectors, reducing the ratio of bonded to free, unbonded restoration surfaces and minimizing the mass of *in situ* cured composite. The relationship between the amount of polymerization shrinkage, polymerization shrinkage stress and marginal adaptation needs further study.

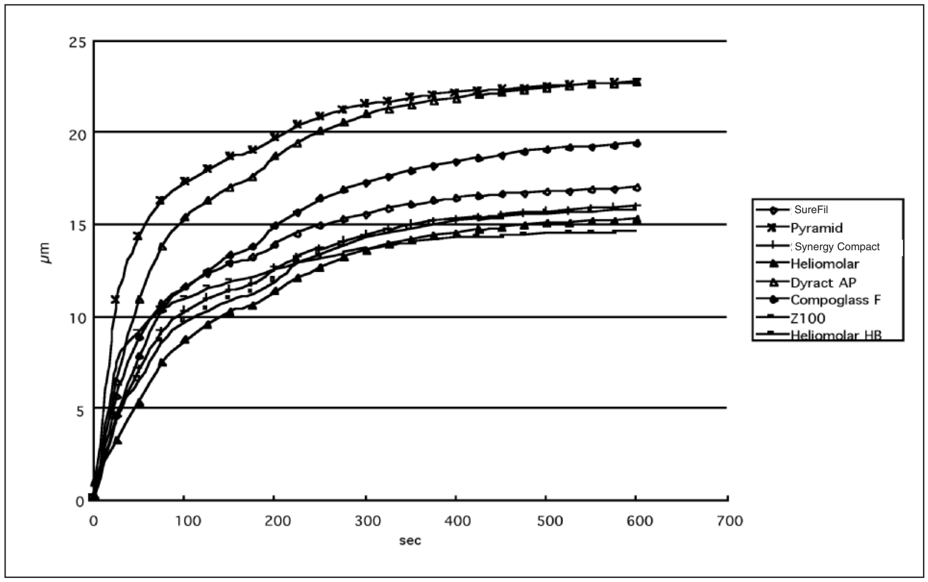

Figure 4: *Amount of cuspal deflection versus time in MOD upper premolar.*

In this study, most of the polymerization shrinkage of composites and polyacid modified resin composites occurred within the first 20 seconds and reached a plateau even though a slight increase continued. This is consistent with previous studies (Park & others, 1999, 2002). However, cuspal deflection was slower and longer than the polymerization shrinkage of composites and compomers and reached a plateau between 300-500 seconds. During the dark polymerization period, even though the absolute polymerization shrinkage amount is smaller, more cuspal deflection may be induced, because the material is stiffer in this period than in the light-curing period. It is also possible that the remaining tooth structure resists flexure in the early phase of the polymerization process and needs further investigation.

In Figure 4, in all groups, there is a slight jump in the cuspal deflection at 180 seconds. In this study, the teeth were irradiated for 180 seconds using a curing lamp of 730mW/cm^2 power density, and the distance between the lamp and cusp tip was 2 mm. Shortall and Harrington (1998) reported that the light curing process led to a temperature rise, and the amount of temperature rise was dependent on the cavity depth, power density of the curing light and shade and opacity of the composites. In the Shortall and Harrington study, when a curing lamp of 710mW/cm^2 was activated for 60 seconds, the temperature rise was 10.70°C at a 2 mm distance from the curing lamp, and when the light was turned off, the temperature dropped sharply. Considering the results of the Shortall and Harrington study, when the curing light turned off after 180 seconds of activation in the current study, the temperature on the tooth surface might drop more than 10.70°C.

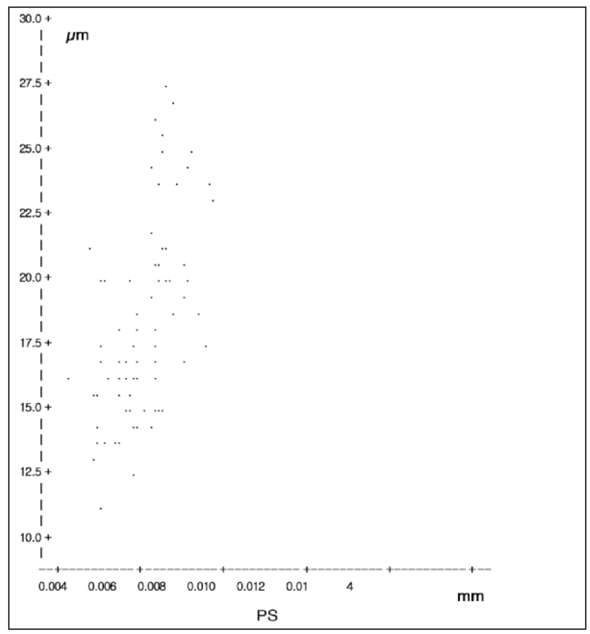

Figure 5: *Scatter plot of the relationship between amount of polymerization shrinkage (PS) amount and cuapal deflection (CD).*

Considering the linear coefficient of thermal expansion is 8.3-11.4 PPM/°C for the tooth and 26.5-43.4 PPM/°C for composites (O'Brien, 2002), when the light turned off after 180 seconds of light activation in this study, several additional μm of linear contraction may occur in tooth and composite when the temperature drops by more than 10°C. This might account for the slight jump of 180 seconds in Figure 4.

In this study, modified MOD cavities 3.5-mm wide and 3-mm deep were prepared in lieu of conventional

MOD cavities. This was to simplify and standardize the cavity design. As the amount of cuspal deflection was relatively small, and the authors had to compare the data between materials, it was particularly important to minimize the variability and control error. A conventional MOD cavity is more complex in design, and small variations in cavity preparation might have influenced the results of cuspal deflection. Therefore, a simpler cavity design was applied.

Abbas and others (2003) reported that the type of curing light (halogen or plasma arc curing) and curing method (bulk or incremental) could affect the amount of cuspal deflection and microleakage. They reported that cuspal deflection was the highest; whereas, microleakage was lowest when the composites were incrementally cured using a halogen lamp. According to their study, bulk curing using a plasma arc lamp induced insufficient composite cure and resulted in lesser cuspal deflection and more leakage. In this study, the bulk curing technique was used to decrease the deviation in data, even though incremental curing is generally recommended in clinical situations. In the pilot of this study, the authors compared bulk and incremental curing methods to determine cuspal deflection. At that time, they found that there were more deviations in cuspal deflection data when incremental curing was used. The movement of cusps during composite manipulation with the incremental technique was considered to induce more deviations in data. To prevent incomplete composite curing, which may occur in bulk curing (Abbas & others, 2003), the composites were cured for 180 seconds (occlusal 60 seconds, mesial 60 seconds, distal 60 seconds) using a halogen lamp.

Heliomolar showed the lowest shrinkage value and was one of the materials that showed the lowest intercuspal deflection. Park and others (2003) and Lim and others (2002) also reported showing the lowest shrinkage stress value. Some of the resin matrix in Heliomolar is in the form of prepolymerized particles that do not contribute to polymerization shrinkage. The characteristics of Heliomolar that have a low amount of shrinkage, low shrinkage stress and low cuspal deflection might be the reason for the long-term clinical success of this material (Christensen, 1997).

In this study, polymerization shrinkage was measured for only 60 seconds. The absolute shrinkage value would be more accurate if the shrinkage measure could be extended for hours. However, the greatest degree of increase in hardness was observed in the first few minutes (Hansen, 1983), and the polymerization shrinkage rate of light-cured composite was greatest during the first 30-40 seconds (Sakaguchi & others, 1992). Thus, in a comparative study, recording the shrinkage value during the first 60 seconds mirrored relative long-term shrinkage values (Park & others, 1999). As this was a comparative study, it was designed to record the shrinkage value for 60 seconds.

Chung and Roh (2004) reported that SE Bond showed relatively high bond strength with diverse restorative composites. If sufficient bond strength was not produced, gaps may be formed between the filling material and tooth, which may influence cuspal deflection. This is the reason why the same bonding system (SE Bond) was used for the different restorative materials.

Table 4 shows the wt % of filler contents of the tested materials provided by the manufacturers. When the authors of this study compared the filler content of the materials in Table 4 and the shrinkage data from this study, it can be seen that high filler content of a filling material does not always guarantee low polymerization shrinkage. Although the space occupied by the filler particles does not participate in curing contraction, high filler loads require low molecular weight monomers to ensure proper handling viscosity. Within certain limits, polymerization shrinkage is not dependent on filler load. The lower molecular weight monomers in packable composites and polyacid modified resin composite, which is added to control the handling viscosity, may be responsible for the higher shrinkage value.

CONCLUSIONS

The amount of linear shrinkage and cuspal deflection were highly correlated.

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