Effect of light-curing units on the thermal expansion of resin nanocomposites

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Abstract

Purpose—To examine the thermal expansion of resin nanocomposites after light-curing using different light-curing units.

Methods—Four different resin nanocomposites and four different light-curing units [quartz-tungsten-halogen (QTH), light emitting diode (LED), laser, and plasma arc] were chosen. Metal dies were filled with resin to make specimens and light-cured. The light intensity and light-curing time of the QTH and LED light-curing units were 1000 mW/cm^2 and 40 seconds, 700 mW/cm^2 and 40 seconds for the laser, and 1600 mW/cm^2 and 3 seconds for the plasma arc. The coefficient of thermal expansion (CTE) was evaluated using a thermomechanical analyzer (TMA) at temperatures ranging from 30–80°C.

Results—The CTE of the resin nanocomposites tested ranged from 28.5 to 65.8 ($\times 10^{-6}$/°C), depending on the product and type of light-curing unit used. Among the specimens Grandio showed the lowest CTE. The specimens cured using the plasma arc unit (Apollo 95E) showed the highest CTE. There was a linear correlation between the CTE and filler content (vol%) (R: −0.94~ −0.99 depending on the light-curing unit). The results may suggest a careful selection of the light-curing unit because there was more expansion in the specimens cured using the plasma arc unit than those cured by the other units. *(Am J Dent* 2010;23:331–334).

Introduction

The advent of nanotechnology has made possible the production of resin composites containing nanosized particles for dental purposes.[1–3] Hybrid resin composites are a mixture of resins and microfillers with various sizes and shapes. Resin nanocomposites contain nanofillers, in the form of nanoparticles and nanoclusters, and microfillers. The nanofillers can increase the filler content (vol%) and improve the continuity between the teeth and

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restorative material. However, since resin nanocomposites have only recently become commercialized, many of their physical properties are not known yet.

The thermal expansion of composite resins in the oral cavity is important because thermal situations can be complicated. A restorative material that bonds to the teeth can undergo dimensional changes under a thermal stimulus if the restorative material and tooth have different thermal expansion properties. A difference in the coefficient of thermal expansion (CTE) between the restorative material and tooth can result in microleakage at the tooth-restorative interface. The CTE of restorative materials relies on the filler content (vol%) and the resins contained. In many cases, there was a linear correlation between the CTE of the resin composites and the filler volume.[4,5] Among the resins contained in the dental resin composites, Bis-GMA (bisphenol A glycol dimethacrylate) is the core resin and has very high viscosity due to its high molecular weight. To enhance the workability, monomers such as TEGDMA (triethyleneglycol dimethacrylate) and/or UDMA (urethane dimethacrylate), were added as diluents. These monomers are of a little lower molecular weight than Bis-GMA. According to this study, these resins have a similar CTE. However, their copolymers mixed with fillers showed a significant decrease in CTE.[6]

To polymerize resin composites, several different light-curing units are available in dentistry: quartz-tungsten-halogen (QTH) lamp-based, light emitting diode (LED)-based, xenon lamp-based, and laser-based. The most common feature on these units is the emission peak near 460 nm, the absorption peak of the photoinitiator which is contained in the resin composites. Both QTH and xenon lamp-based plasma arc units have a similar light emission pattern. The emission spectrum distributes at 400–500 nm. LED-based units have a narrower emission bandwidth than that of QTH lamp-based units. Laser-based units have not been generalized in dentistry on account of their high price and limited applications in dentistry. However, since laser has excellent features, such as monochromaticity, coherence and brightness as a light source, many studies have used laser to examine the polymerization of resin composites.[7–10] Among the lasers, the argon laser has been studied extensively in the polymerization of resin composites.

This study evaluated the coefficient of thermal expansion of resin nanocomposites which were light-cured using different light-curing units under the conditions that clinicians usually take. Through the study, the performance of light-curing units for the polymerization of resin nanocomposites was assessed.

Materials and Methods

In this study, four different resin nanocomposites [Ceram X[a] (CX), Filtek Supreme[b] (FS), Grandio[c] (GD), Filtek Z350[b] (Z3)] were used, and their characteristics are listed in Table 1. For light-curing, four different light-curing units [L.E. Demetron 1[d] (DE), DPSS[e] laser (LAS), Optilux 501[f] (OP), Apollo 95E[g] (PLA) were used, and they are listed in Table 2. The emission spectrum of each light-curing unit and the absorption spectrum of CQ were measured using a photodiode array detector (M1420[h]) that was connected to a spectrometer (SpectroPro-500[i]). To measure the absorption spectrum of CQ, the dissolved CQ powder in

ethanol was used. Twenty specimens ($1.5 \times 2 \times 12$ mm) per product were prepared to evaluate the CTE of the specimens. Each resin was placed into a metal die and polymerized using four different light-curing units. The light intensity of the light-curing units was 1000 mW/cm^2 for DE and OP, 700 mW/cm^2 for LAS, and 1600 mW/cm^2 for PLA. The light-curing time was 40 seconds for DE, LAS, and OP but only 5 seconds for PLA. The output light intensity of DE, OP, and PLA was measured using a radiometer. The emission wavelength of the DPSS laser was 473 nm. The output power and spot size of the LAS beam were approximately 200 mW (PM3/FIELDMAX[j]) and 6 mm, respectively. The resin in the metal die was covered with a thin (200 μm) transparent cover glass. The end of the light guide (DE, OP, and PLA) was placed in contact with the cover glass during the light-curing process. In the case of LAS, the light was delivered without a light guide. The unexposed rear side was light polymerized for 40 seconds after removing each specimen from the metal die. This was carried out to ensure complete polymerization. The specimens were stored in a dark container for 24 hours before taking the measurements. Five specimens from each product were selected for each light-curing unit. The CTE was evaluated using a thermomechanical analyzer (TMA) (TMA120[k]). The linear expansion (displacement) of the specimen was recorded at temperatures ranging from 30~80°C. Each specimen was subjected to heat at a rate of 5°C/minute to obtain a uniform heat distribution. Only one measurement per specimen was recorded in order to reduce the additional polymerization shrinkage caused by the elevated temperatures during the measurements. After each measurement, the machine was cooled to < 30°C. The CTE was evaluated at temperatures ranging from 30~80°C using internal software from the TMA.

The CTE values were analyzed by a two-way ANOVA for the product and light-curing unit followed by a Tukey's test. All results were analyzed at a significance level of 5%.

Results

Figure 1 shows the emission spectrum of each light-curing unit along with the absorption spectrum of the photoinitiator, CQ. The emission spectra of the light-curing units matched the CQ absorption peak. Of the light-curing units examined, LAS showed the most narrow emission bandwidth. Both OP and PLA showed a similar spectral distribution, and were the ones that matched CQ most closely.

Table 3 shows the CTE ($\times 10{-}6$/°C) in the temperature range, 30~80°C, of the various resin products and light-curing units. Regardless of the light-curing unit used, GD showed the lowest CTE. Regardless of the resin product used, specimens light-cured with PLA had the highest CTE for all the light-curing units. The CTE of GD (in terms of product) and the resins cured by PLA (in terms of light-curing unit) were significantly different from the values obtained from the different products and different light-curing units (P<0.05).

Figure 2 shows the relationship between the displacement (change in specimen length) and increase in temperature during heating. The specimens (Z3) cured using PLA showed considerably greater displacement *(i.e.,* much greater thermal expansion) than those cured with the other light-curing units (Fig. 2a). When using the same light-curing unit, GD showed much less displacement than that of the other products (Fig. 2b).

Figure 3 shows an inverse relationship between the filler content (vol%) and CTE of DE. The correlation coefficient ranged from −0.94 to −0.99 depending on the light-curing unit used.

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[j]Coherent, Portland, OR, USA.
[k]Seiko, Tokyo, Japan.

Discussion

Resin composites containing nanofillers (size of 0.1~100 nm) have recently become available. The potential advantages of containing nanofillers include increased filler volume and better translucency. Within the resin matrix, the empty free space made by the microfillers can become filled with nanofillers even though these fillers are not easily differentiated due to their similar size, which can increase the overall filler volume. In many cases, the increase in filler volume by nanofillers can improve the physical/mechanical properties of the specimens because the physical/mechanical properties of resin specimens are related to the filler loading. In addition, the improved continuity can increase the strength and durability of the specimens.[11–13] In this study, three products (CX, FS, Z3) showed similar filler volumes (57~59.5 vol%), whereas the filler volume of GD was much higher (71.4 vol%).

The profile of the emission spectrum is the main difference regarding the light-curing units used. OP and PLA have a similar emission profile and match the absorption spectrum of CQ most closely. DE was closer to the absorption peak of CQ. LAS has the narrowest emission width among the light-curing units used. The light intensity of DE and OP was identical ($1000 mW/cm^2$). The light intensity of PLA and LAS was 1600 and 700 mW/cm^2, respectively. The specimens cured using these light-curing units showed different thermal expansion coefficients. Among them, the specimens cured using PLA showed the highest coefficient, even though PLA showed the highest light intensity. Regarding polymerization, if the specimens are less polymerized, they become soft and can expand more easily than those that are fully polymerized (hard). All specimens cured using PLA showed the highest CTE (the greatest displacement value during heating) compared with those cured using the other light-curing units. The 5-second irradiation time with PLA is a short time for achieving sufficient polymerization. However, insufficient polymerization by PLA has been suggested by many studies.[14–16] The specimens cured using LAS had a similar CTE to the other specimens cured using DE and OP, whereas their light intensity was much higher than that of LAS. A low light intensity with a narrow emission wavelength near the absorption peak of CQ appears to have a similar effect to the light of a high intensity but an emission wavelength wide enough to cover the entire absorption spectrum of CQ. The lower CTE in the specimens with the higher filler content is reasonable because the CTE of an inorganic filler [approximately 0.5~6 ($\times 10^{-6}/°C$)] is much lower than that of the organic matrix (resin) [approximately 110~190 ($\times 10^{-6}/°C$)].[17] Therefore, as the filler volume increases, the contribution from the highly-expanding organic matrix is reduced resulting in less expansion.

In this study, the specimens tested showed an inverse correlation (r=−0.99 for DE, LAS, and for OP; −0.94 for the specimens cured with PLA) between the filler content and the CTE. With the exception of GD, the CTE of the resin composites containing nanofillers was similar to that of the resin composites that did not contain nanofillers.[18] Although it is difficult to compare the CTE values obtained under different experimental conditions, the CTE values obtained in this study and other reports are much greater than those for enamel and dentin: 17 ($\times 10^{-6}/°C$) and 11 ($\times 10^{-6}/°C$), respectively.[4,19,20] The difference in the CTE values between the restorative materials and host teeth might increase the amount of microleakage within theoral cavity. Microleakage can lead to secondary caries, restoration failure and postoperative sensitivity.[21–23] Therefore, one criterion that can be considered for a better restoration is the selection of a material with a high filler content.

The tested specimens contain some or all of the Bis-GMA, Bis-EMA, TEGDMA, and UDMA resins. TEGDMA and/or UDMA are usually added to Bis-GMA to reduce the viscosity of Bis-GMA and achieve a workable copolymer. The CTE of these resins ranged

from approximately 100–194 ($\times 10^{-6}$/°C) at temperatures ranging from 0–60°C.[6] High CTE values of the resins remained similar even when specimens formed copolymers by combining resins. However, once the copolymers contain fillers, their CTE value decreases significantly [approximately 23~48 ($\times 10^{-6}$/°C)].[6,24,25] Overall, the CTE of resin composites depends mainly on the filler content and the state of the resins.

In conclusion, the CTE of the tested specimens was much higher than that of enamel and dentin. The specimens cured using PLA showed the highest CTE. The highest CTE appears to be related to insufficient polymerization. High light intensity with a short curing time did not appear to be effective for sufficient polymerization. On the other hand, a low intensity with an extremely narrow emission wavelength (LAS) near the absorption peak of CQ appears to facilitate the polymerization of nanocomposites. DE, LAS and OP appear to produce a similar degree of polymerization in the resin nanocomposites. The specimens light-cured using the above three light-curing units had a similar CTE.

Acknowledgments

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Clinical significance

Within the limitations of this study, the resin nanocomposites evaluated showed much higher CTE than the enamel and dentin. The plasma arc unit produced a significantly higher CTE than the other units due to the incomplete polymerization of the materials.
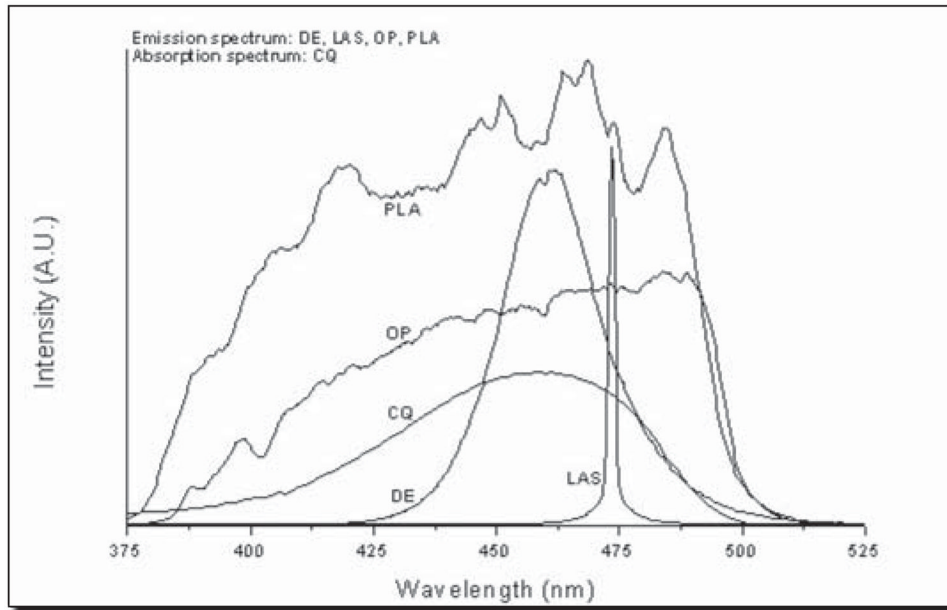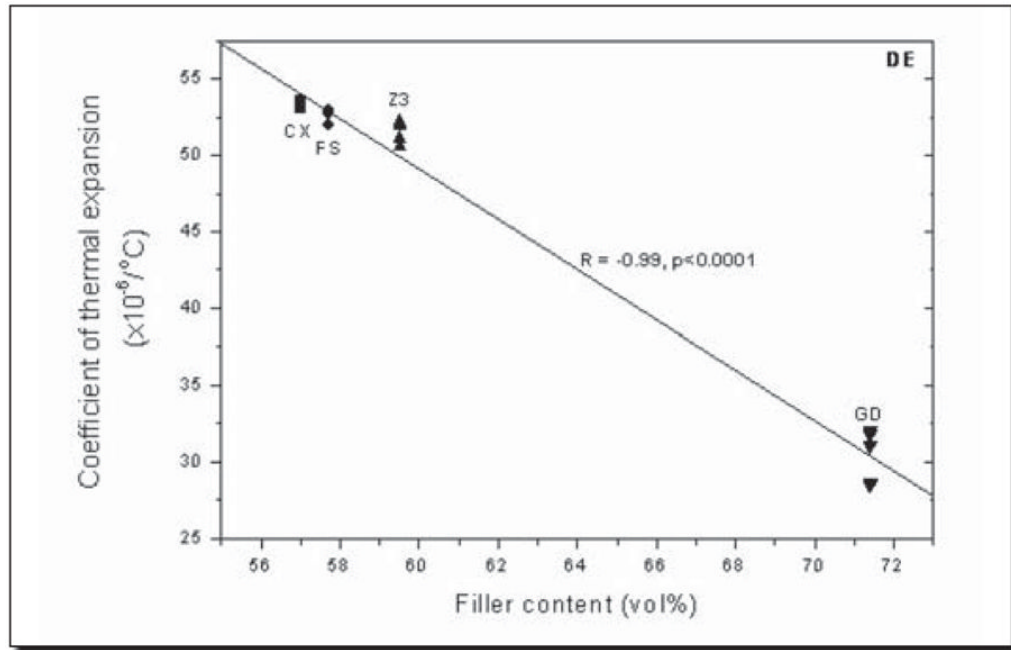
Fig. 1.
Emission spectra of the used light-curing units and the absorption spectrum of CQ.
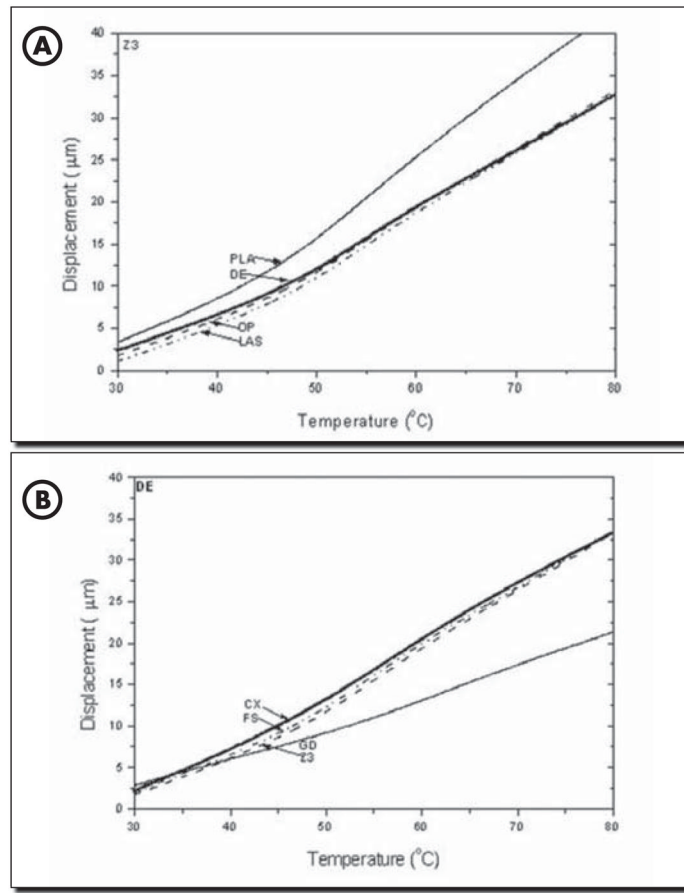
Fig. 2.
Relationship between displacement (change in specimen's length) and temperature rise during heating (**A.** Z3 light cured with different light-curing units; **B.** resin products light cured with DE).

Fig. 3.
Relationship between filler content (vol%) and the CTD of DE.

Table 1

Characteristics of resins tested in this study.

	Composition	Filler type	Filler* vol%/wt%
CX	Methacrylate modified polysiloxane dimethacrylate resin	Ba-Al-borosilicate glass, methacrylate functionalized SiO_2, nanofiller	57/76
GD	Bis-GMA, TEGDMA, UDMA	Ba-Al-borosilicate Glass filler, SiO_2 nanofillers	71.4/87
Z3	Bis-GMA, UDMA, TEGDMA, Bis-EMA	Non-aggregated zirconia/silica	59.5/78.5

CX: Ceram X; GD: Grandio; Z3: Filtek Z350.

*
: According to the manufacturers.

Table 2

Light-curing units used in this study.

Code	Name	Classification
DE	L.E.Demetron 1	LED
LAS	DPSS (diode-pumped solid state state)	Laser
OP	Optilux 501	Conventional light (QTH lamp-based)
PLA	Apollo 95E	Plasma arc light (Xenon lamp-based)

Table 3

CTE ($\times 10^{-6}/°C$) of specimens that were light cured with different light-curing units.

	DE[12]	LAS[1]	OP[2]	PLA[3]	P-values
CX[A]	53.2 ± 0.3	54.0 ± 0.8	52.5 ± 0.6	58.5 ± 2.6	$\alpha < 0.001$
FS[A]	52.3 ± 0.5	56.5 ± 2.3	50.8 ± 1.4	65.8 ± 3.1	$\beta < 0.001$
GD[B]	30.5 ± 1.8	29.6 ± 0.3	28.5 ± 0.7	33.2 ± 1.2	$\alpha*\beta < 0.001$
Z3[A]	51.6 ± 0.9	53.4 ± 0.6	51.2 ± 1.5	65.6 ± 4.1	

* Statistically significant difference within rows is shown by superscript letters[A,B], within columns by superscript numbers[1,2,3]. Same letters or numbers are not significantly different ($P < 0.05$).

* On P-values, the letters α, β, and $\alpha*\beta$ denote resin product, light-curing unit, and interaction of two factors, respectively.