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Time-based Elution of TEGDMA and BisGMA from Resin Composite Cured with LED, QTH and High-intensity QTH Lights

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Clinical Relevance

Under the conditions of this study, when compared to standard QTH, both standard LED and high-intensity QTH light curing resulted in lower levels of the elution of TEGDMA, which is suspected to be the prime cause of cytotoxic reactions in resin composite restorations.

SUMMARY

This study measured the elution of TEGDMA and BisGMA monomers from hybrid, micro-filled resin composites over 72 hours at different time intervals after polymerization with standard quartz-tungsten-halogen (QTH), high-intensity fast-curing QTH and standard blue light emitting diode (LED) light units. Samples were polymerized from the top and bottom surfaces, then immersed in methanol. High performance liquid chromatography (HPLC) was used to measure the amount of monomers released from the samples at various time intervals, ranging from 0 to 72 hours (0, 3, 6, 9, 12, 24, 48 and 72 hours). Data was analyzed using two-way ANOVA and Duncan tests with a significance level of 0.05. No significant differences were observed among curing groups in the elution of TEGDMA monomers at 0, 9, 12, 24, 48 and 72 hours; whereas, significant differences were observed among curing groups at 3 and 6 hours. BisGMA elution in samples immersed for longer periods (9-72 hours) were significantly higher than samples immersed for shorter time periods (0-6 hours); however, 72 hours appeared to be too short a period for the total elution of BisGMA into methanol.

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INTRODUCTION

Recently, a number of dental composites have been developed based on 2,2 bis[4-(2-hydroxy-3-methacryloxypropoxy) phenyl]-propane (BisGMA) combined with triethyleneglycol dimethacrylate (TEGDMA), which is often used as a diluent monomer (Peutzfeldt, 1997). In resin composites, a significant amount of residual monomers or short-chain polymers remain unbound even after curing. The elution of these unbound molecules into aqueous media (Ferracane, 1994; Muller,

Table 1: *Restorative Material Used in This Study*

Material	Code	Manufacturer	Resin	Filler	Filler Size (μm)	Filler Content (% by volume)	Lot #
Charisma	CHR	Heraeus Kulzer Dormagen, Germany Shade A2	BisGMA TEGDMA	Barium aluminum boronsilicate glass, pyrogenic silicon dioxide	0.01-0.04	60	3310A2D
Filtek A110	FLT	3M, St Paul, MN, USA Shade A2	BisGMA TEGDMA	Colloidal, Silica	0.01-0.09	40	120058

Table 2: *LCUs and Irradiation Protocols Used in This Study*

	Curing Protocol	Light Curing Unit	Tip (mm)	Curing Mode
Group I	Standard QTH curing	Optilux (Demetron, Kerr, Danbury, CT, USA) Serial #4223926	11	600mW/cm^2 for 40 seconds
Group II	High-intensity fast-curing QTH	Hilux Ultra Plus (Benlioglu Dental, Ankara, Turkey) Serial #P2080878	9 (Turbo)	1400mW/cm^2 for 10 seconds
Group III	Standard LED curing	Elipar Freelight (3M ESPE, Germany) Serial #939800001010	8	400mW/cm^2 for 40 seconds

Olsson & Soderholm, 1997; Munksgaard, Peutzfeldt & Asmussen, 2000; Geurtsen & Leyhausen, 2001) has been a topic of investigation, because of the potential impact on the biocompatibility and structural stability of restorations (Ferracane, 1994).

A high amount of leachable monomers in a resin composite may indicate poor conversion and, consequently, poor mechanical properties (Asmussen, 1982). The amount of TEGDMA and BisGMA leached from resin-based composites is predominantly dependent on the monomer-polymer conversion (Geurtsen & Leyhausen, 2001). In order to minimize the amount of leachable monomers from resins and resin composites, they must be cured to a high degree (Munksgaard & others, 2000).

Light curing units (LCUs) that utilize very high intensity light are almost universally recommended. These recommendations are generally based on the shorter curing times required when using high-intensity lights with physical and mechanical properties comparable to those of quartz-tungsten-halogen (QTH) lights (Rueggeberg, Caughman & Curtis, 1994; Yap, Wong & Siow, 2003). LCUs that employ a light concentration tip (Turbo Tip, Benlioglu Dental, Ankara, Turkey) can produce power densities of up to 1000 mW/cm^2. Under certain clinical conditions, the use of higher intensity light can shorten the exposure time required for curing (Yap & others, 2003). However, the use of high-intensity light in the polymerization of restorative materials has also been reported to result in high polymerization shrinkage stress (Feilzer & others, 1995; Unterbrink & Muessner, 1995) and adverse biological effects, such as cell death (Wataha & others, 2004).

Recently, manufacturers have turned their attention to light sources used to convert composite materials from monomers to polymers. Studies have looked at the relationship between curing source intensity and exposure duration, thickness of overlying material and tip-to-tooth curing distance in order to determine the optimal conditions for resin curing (Rueggeberg & others, 1994; Dlugokinski, Caughaman & Rueggeberg, 1998). For a number of years, QTH lamps have been used in the polymerization of restorative materials. With QTH lamps, curing is normally accomplished within 40 seconds of light exposure (Munksgaard & others, 2000). Despite their popularity, QTH technologies have several drawbacks (Jandt & others, 2000). QTH lamps have a limited effective life span; reflectors and filters degrade over time, thus reducing the amount of light output (Mills, Jandt & Ashworth, 1999). To overcome problems inherent in QTH LCUs, solid state light emitting diode (LED) technology has been proposed for the curing of light-activated dental material (Mills, 1995). Recently, several studies have been conducted on the use of blue LED technology in polymerization (Mills, 1995; Mills & others, 1999; Jandt & others, 2000; Soh, Yap & Siow, 2003; Tsai, Meyers & Walsh, 2004).

This study measured the elution of TEGDMA and BisGMA monomers from hybrid, micro-filled resin composites at set time intervals from 0 to 72 hours following polymerization with standard QTH, high-intensity fast-curing QTH and standard LED light curing units.

METHODS AND MATERIALS

Two types of BisGMA- and TEGDMA-based resin composites—the hybrid composite Charisma (CHR) (Charisma, Heraeus, Kulzer, Dormagen, Germany) and the microfilled composite Filtek (FLT) (A110, 3M, St Paul, MN, USA)—were used in this study (Table 1). The two composites are very similar in terms of monomer composition; both contain BisGMA and TEGDMA in their resin matrixes and camphoroquinone as a photoinitiator. The main difference between the two composites is in the type and percentage of filler.

The composites were placed in stainless steel molds (6.0-mm diameter, 2-mm high), and their surfaces covered with transparent mylar matrix strips. They were sandwiched between 1-millimeter thick glass slides in order to ensure smooth surfaces, minimize the inhibition of polymerization by oxygen and extrude excess material through the application of pressure (Yap & others, 2004). The top slide was removed and the material cured from the top surface using either a standard QTH curing unit (Optilux, Demetron, Kerr, Danbury, CT, USA), a high-intensity QTH fast-curing unit (Hilux Ultra Plus, Benlioglu Dental, Ankara, Turkey) or a standard LED curing unit (Elipar FreeLight, 3M ESPE, Seefeld, Germany). The bottom slide was then removed and the material cured from the bottom surface as described above. The following curing protocols were used in this study (Table 2):

Group I (Control): QTH standard curing unit; Exposure time: 40 seconds at 600mW/cm^2.

Group II: High-intensity QTH fast curing unit; Exposure time: 10 seconds at 1400mW/cm^2.

Group III: LED standard curing unit; Exposure time: 40 seconds at 400mW/cm^2.

All samples were prepared by the same clinician in a temperature-controlled room (23°C). A curing radiometer (Curing radiometer, Model 100, Demetron, Kerr) was used to measure the intensity of the QTH light before each application in Group I; whereas, the light intensity in Group II was measured by a curing radiometer within the QTH unit, which was monitored prior to each application. In the case of Group III, the light intensity stated by the LED unit manufacturer was accepted as being accurate. The LED unit's batteries were recharged according to the manufacturer's recommendations and the units were replaced in their chargers following polymerization of each sample.

Immediately after curing, the specimens were weighed, placed in black vials containing 5 mL of high performance liquid chromatography (HPLC)-grade methanol (Riedel de Häen 34680, Germany) and sealed to prevent evaporation of volatile material. Samples were immersed immediately after polymerization rather than after a 24-hour curing period in order to more closely simulate clinical conditions (Ferracane & Condon, 1990). Five samples were measured for each of the different storage periods, which varied from 0 (2-3 seconds) to 3, 6, 9, 12, 24, 48 and 72 hours. The samples were stored at room temperature until analysis.

The samples were extracted and the remaining solutions filtered. Aliquots were transferred to automatic liquid sampler vials with flat-bottomed glass inserts and crimp seals. Analysis was conducted by reverse-phase HPLC using a Thermo-Finnigan Surveyor system (Thermo Finnigan, Hemel, Hempstead, UK) comprised of a pump, an auto sampler, a photo diode array detector (PDA) and an SS Wakosil II 5 C18RS (250 mm x 4.6 mm, 5 µm) HPLC column (SGE, UK). Chromatographic conditions are shown in Table 3. Chromatograms were recorded and processed using the Chromquest software package version 2.51 (Thermoquest Corporation, Manchester, UK). A linear regression equation obtained from calibration graphs was used to compare peak retention times and absorbance characteristics with those of TEGDMA (Aldrich, 26,154-8, Chemical Co, Milwaukee, WI, USA) and BisGMA (Aldrich, 41,116-7, Chemical Co) monomer standards. All measurements were taken in duplicate and the results evaluated according to peak areas (Munksgaard & others, 2000). The results were recorded in ppm (µg/g) at set intervals for up to 72 hours immersion (Yap & others, 2004).

Two-way analysis of variance (ANOVA) and Duncan tests were used to analyze data on the amount of monomer eluted by monomer type, elapsed time and light curing protocol. Statistical analysis was conducted at a significance level of $p<0.05$.

Table 3: *HPLC Conditions Used in This Study*

Column	**(250 mm x 4.6 mm, 5 µm) SS Wakosil II 5 C18RS, SGE, UK**
Mobile phase	Solvent: 20% water and 80% methanol (isocratic mode)
Flow rate	1.0 mL/minute
Temperature	25°C
Detector	PDA 200-360 nm
Injection volume	25 µL
Analysis time	20 minutes

RESULTS

Tables 4 and 5 show the mean amounts of BisGMA and TEGDMA released from the CHR and FLT sample groups at set intervals (0, 3, 6, 9, 12, 24, 48 and 72 hours) following immersion in methanol.

Figure 1 shows the trend in TEGDMA and BisGMA elution into methanol from the CHR and FLT samples for each of the three curing groups over a 72-hour period. There was no significant difference in

Table 4: *Mean TEGDMA and BisGMA Release (ppm) from CHR Samples into Methanol at Set Time Intervals (0, 3, 6, 9, 12, 24, 48 and 72 hours)*

	TEGDMA (ppm)			BisGMA (ppm)		
Immersion Time (hours)	**Group 1 mean ± sd**	**Group 2 mean ± sd**	**Group 3 mean ± sd**	**Group 1 mean ± sd**	**Group 2 mean ± sd**	**Group 3 mean ± sd**
0 hours	0.32 ± 0.03[a]	0.34 ± 0.02[a]	0.32 ± 0.01[a]	0.08 ± 0.00[g]	0.08 ± 0.00[g]	0.08 ± 0.00[g]
3 hours	1.88 ± 0.18[b]	1.45 ± 0.24[c]	1.39 ± 0.14[c]	0.33 ± 0.03[h]	0.33 ± 0.03[h]	0.36 ± 0.01[h]
6 hours	2.16 ± 0.23[d]	1.88 ± 0.30[e]	1.72 ± 0.16[e]	0.37 ± 0.03[h]	0.39 ± 0.05[h]	0.42 ± 0.01[h]
9 hours	3.83 ± 0.43[f]	3.86 ± 0.08[f]	3.91 ± 0.07[f]	2.50 ± 0.13[i]	2.53 ± 0.07[i]	2.12 ± 0.11[j]
12 hours	3.88 ± 0.70[f]	3.93 ± 0.28[f]	4.01 ± 0.14[f]	2.89 ± 0.18[k]	3.33 ± 0.10[L]	3.47 ± 0.12[m]
24 hours	4.07 ± 0.07[f]	4.09 ± 0.04[f]	4.20 ± 0.08[f]	3.42 ± 0.18[n]	3.86 ± 0.10[p]	4.00 ± 0.12[r]
48 hours	4.07 ± 0.04[f]	4.19 ± 0.06[f]	4.22 ± 0.06[f]	4.03 ± 0.13[r]	4.06 ± 0.07[r]	4.03 ± 0.12[r]
72 hours	4.20 ± 0.03[f]	4.28 ± 0.06[f]	4.26 ± 0.07[f]	4.39 ± 0.18[s]	4.83 ± 0.10[t]	4.97 ± 0.12[u]

Results for groups identified with the same superscript letter were not significantly different (two-way ANOVA, Duncan, p>0.05).

Table 5: *Mean TEGDMA and BisGMA Release (ppm) from FLT Samples into Methanol at Set Time Intervals (0, 3, 6, 9, 12, 24, 48 and 72 hours)*

	TEGDMA (ppm)			BisGMA (ppm)		
Immersion Time (hours)	**Group 1 mean ± sd**	**Group 2 mean ± sd**	**Group 3 mean ± sd**	**Group 1 mean ± sd**	**Group 2 mean ± sd**	**Group 3 mean ± sd**
0 hours	0.42 ± 0.04[a]	0.45 ± 0.01[a]	0.47 ± 0.06[a]	0.11 ± 0.00[g]	0.10 ± 0.00[g]	0.10 ± 0.00[g]
3 hours	2.39 ± 0.23[b]	1.84 ± 0.10[c]	1.90 ± 0.12[c]	0.42 ± 0.04[h]	0.47 ± 0.01[h]	0.37 ± 0.01[h]
6 hours	2.85 ± 0.28[d]	2.37 ± 0.25[e]	2.26 ± 0.07[e]	0.47 ± 0.03[h]	0.55 ± 0.03[h]	0.41 ± 0.00[h]
9 hours	4.84 ± 0.26[f]	4.79 ± 0.23[f]	4.85 ± 0.10[f]	3.29 ± 0.13[i]	3.25 ± 0.14[i]	2.89 ± 0.21[j]
12 hours	4.97 ± 0.24[f]	4.94 ± 0.07[f]	4.98 ± 0.15[f]	3.92 ± 0.32[k]	4.41 ± 0.07[L]	4.46 ± 0.09[m]
24 hours	5.14 ± 0.19[f]	5.15 ± 0.07[f]	5.18 ± 0.03[f]	4.61 ± 0.32[n]	5.10 ± 0.07[p]	5.15 ± 0.09[r]
48 hours	5.25 ± 0.11[f]	5.35 ± 0.07[f]	5.31 ± 0.02[f]	5.79 ± 0.13[r]	5.76 ± 0.14[r]	5.41 ± 0.15[r]
72 hours	5.35 ± 0.10[f]	5.37 ± 0.08[f]	5.38 ± 0.07[f]	5.87 ± 0.32[s]	6.36 ± 0.07[t]	6.41 ± 0.09[u]

Results for groups identified with the same superscript letter were not significantly different (two-way ANOVA, Duncan, p>0.05).

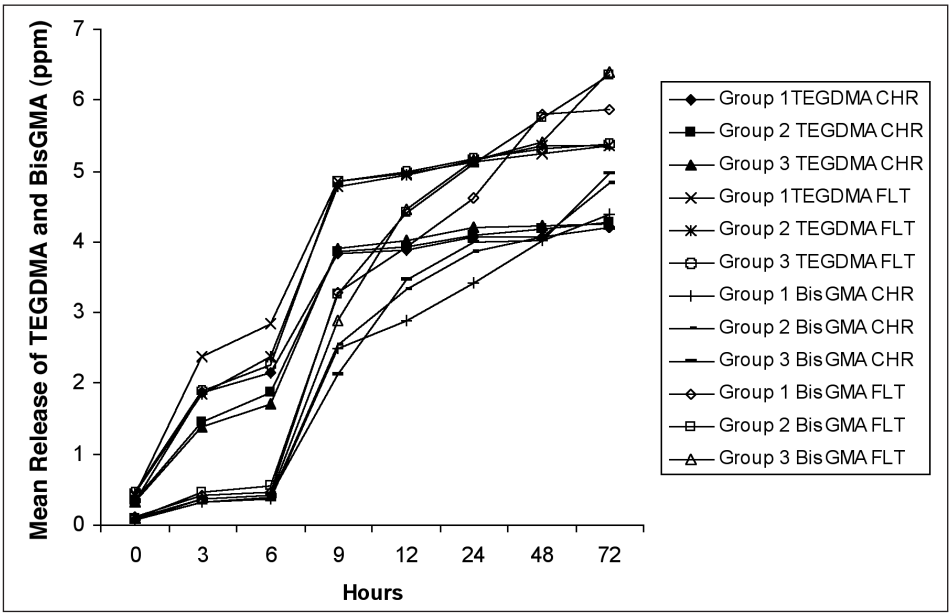

Figure 1: *Elution of TEGDMA and BisGMA from cured CHR and FLT samples into methanol over a 72-hour period for Group I (QTH standard curing unit; Exposure time: 40 seconds at 600mW/cm^2), Group II (High-intensity QTH fast curing unit; Exposure time: 10 seconds at 1400mW/cm^2) and Group III (LED standard curing unit; Exposure time: 40 seconds at 400mW/cm^2).*

mean elution of TEGDMA from either CHR or FLT composites among Groups I, II and III at 0, 9, 12, 24, 48 or 72 hours. However, at 3 hours and 6 hours, TEDGMA elution from both CHR and FLT in Group I (standard QTH) showed significant differences when compared to Group II (high-intensity QTH) and Group III (standard LED).

At 0, 3 and 6 hours, there were no significant differences in the mean elution of BisGMA from either CHR or FLT composites among Groups I, II and III. However, when the length of immersion time was increased from 9 to 72 hours, significant differences were observed among the groups ($p<0.05$), and these differences increased from 9 to 72 hours. At 72 hours, mean amounts of BisGMA

released from CHR composite varied from a low of 4.39 ppm (Group I) to a high of 4.97 ppm (Group III); whereas, mean amounts of BisGMA released from FLT composite varied from a low of 5.87 ppm (Group I) to a high of 6.41 ppm (Group III).

DISCUSSION

Several factors contribute to the process of elution from dental composites, such as size and chemical composition of the leachable substance and chemistry of the solvent (Ferracane, 1994). The rate and extent of elution has been reported to be greater in an organic solvent when compared to elution into pure water (Asmussen, 1982; Ferracane, 1994; Muller & others, 1997; Spahl, Budzikiewicz & Geurtsen, 1998; Munksgaard & others, 2000; Geurtsen & Leyhausen, 2001). For this reason, in order to measure the elution of high molecular weight monomers such as BisGMA, organic solvents such as methanol are preferred.

The polymerization of light-cured resin depends not only on the quantity of light, but also on its quality, including such factors as wavelength (Yoon & others, 2002). It is generally accepted that an intensity of 300 mW/cm^2 or greater at a wavelength range of 450-500 nm (peak absorption at 470 nm) is needed for complete polymerization of composites up to 2 mm in thickness (Lee & others, 1993). However, several authors have suggested different intensities (Rueggeberg & others, 1994; Unterbrink & Muessner, 1995) and curing times for optimal polymerization (Munksgaard & others, 2000; Yap & others, 2003). This study used a standard QTH light intensity of 600 mW/cm^2, with an irradiation time of 40 seconds (manufacturer's recommended cure time) as a control. To ensure uniform and maximum polymerization, 2-mm thick composite samples were used. Moreover, to minimize the effect of colorants on light penetration, a shade of A2 was selected (Bayne, Heymann & Swift, 1994).

Measuring surface hardness at both the top and bottom of resin composites provides a good indicator of the degree of polymerization (Pilo, Oelgiesser & Cardash, 1999; Moon & others, 2004). Length of exposure and light intensity play greater roles in polymer conversion at the top surface of the composite (Rueggeberg & others, 1994), where intensity must be sufficient for the activation of photo-initiator molecules (Yap, Soh & Siow, 2002). As light passes through the bulk of the restorative material, light absorption and scattering by resin composite greatly decreases light intensity, thus decreasing the potential for cure (Asmussen, 1982; Soh & others, 2003). Many studies have found significant differences in the microhardness of top and bottom surfaces of cured composites (Pilo & others, 1999; Yap & others, 2002; Yap & others, 2003; Moon & others, 2004; Tsai & others, 2004). In order to account for these differences when measuring the elution of TEGDMA and BisGMA, resin samples in this study were cured from both the top and bottom surfaces.

This study found similar rates of TEGDMA leaching from CHR and FLT samples over 9 to 72 hours for all three curing groups. As seen in Figure 1, this study found high-intensity QTH fast-curing at 1400 mW/cm^2 for 10 seconds provided optimal curing for CHR and FLT resin composites; however, this result may not be valid for all commercial resin composites. Christensen and others (1999) and Yap and others (2003) have shown that the effect of curing methods on composite cure is material-dependent and that resin formulation, rather than light type or curing mode, is the most important factor in polymerization success or failure. On the other hand, higher light energy densities have been shown to result in decreased residual monomer levels and lower rates of elution (Sakaguchi, Douglas & Peters, 1992; Soh & others, 2003). In addition, Munksgaard and others (2000) reported that photo-initiator efficiency varies according to its type and concentration within the composite. With this in mind, and in view of the substantial time saved, the use of high-intensity light may be a viable method for the clinical polymerization of resin composites (Yap & others, 2003).

Several studies have addressed the use of blue LED technology in the curing of dental material (Mills, 1995; Mills & others, 1999; Jandt & others, 2000; Soh & others, 2003; Tsai & others, 2004). While it has been suggested that standard LED light may produce a significantly greater depth of cure than QTH light (Mills & others, 1999), Yoon and others (2002) reported no differences in curing depth between composites cured using LED lights and those cured using conventional QTH lamps. Unlike QTH lamps, LEDs produce blue light via a combination of different semiconductors. One particular advantage to this kind of technology is the output of a narrow spectral range that peaks around 470 nm—the optimum absorption wavelength for activation of the photo-initiator camphoroquinone (Mills & others, 1999). LED lights are also superior to incandescent lamps in terms of their low voltage, long-life expectancy and resistance to shock and vibration (Mills, 1995; Tsai & others, 2004).

Yap and others (2004) demonstrated that, despite the differences in energy density (intensity x time) between standard LED and QTH curing modes, the analysis of elution of leachable components showed there were no differences in residual TEGDMA and BisGMA monomers in composites polymerized using standard QTH light when compared to standard LED lights. The LED curing lights used in this study provided adequate polymerization. Despite differences in methodology, this data is in agreement with other studies (Mills & others, 1999; Yoon & others, 2002; Soh & others, 2003; Tsai & others, 2004, Yap & others, 2004).

Numerous studies have suggested that TEGDMA is the prime cause of cytotoxic reactions in resin composite restorations (Muller & others, 1997; Geurtsen & Leyhausen, 2001). Cytotoxic aqueous resin elutes have frequently been found to contain high amounts of TEGDMA, indicating that TEGDMA can easily be released in the humid oral environment (Geurtsen & Leyhausen, 2001).

Despite of the fact that there were statistically significant differences between groups at different time intervals, similar results were obtained from both composites over the three curing methods. In this study, the amount of TEGDMA leached over 9 to 72 hours was approximately the same for both composites, regardless of the LCU used in polymerization (Figure 1), indicating that 9 hours is sufficient for TEGDMA to be released in methanol. However, with immersion times of 3 and 6 hours, the elution of TEGDMA was significantly higher in samples polymerized with standard QTH light (Group I) when compared to high-intensity QTH light (Group II) and standard LED light (Group III). This may be due to higher amounts of TEGDMA remaining at surfaces of samples polymerized using standard QTH light curing units (Group I), a result of a more homogenous polymerization of composite with standard QTH light as compared to higher levels of surface polymerization and lower levels of interior polymerization in composites cured using standard LED light and, due to the reduced curing time, high-intensity fast-curing QTH light. While TEGDMA monomers may be quickly released from the composite surface, the release of TEGDMA monomers from the inner layers of the composite requires more time due to the high degree of cross-linking at the surface. This is in line with the findings of Tsai and others (2004), who reported increases in surface hardness of composite polymerized with high-intensity light. Mills and others (1999) reported significantly deeper levels of polymerization in medium-shade hybrid and micro-filled composites cured using LED light when compared to QTH light. These authors also pointed out that the narrow emission peaks of blue LED units indicate that they are more effective than QTH light units. Soh and others (2003) reported that the light output of an LED unit is dependent on the size of the LED rather than the number of LEDs. Their study found that the effectiveness of curing at the top and bottom surfaces of composites polymerized using an LED unit was comparable to that of a conventional QTH unit.

The amount of BisGMA monomers leached at various time intervals (Figure 1) did not differ by light type or curing method. Upon increasing the immersion period from 9 to 72 hours, the amount of BisGMA released also increased significantly for all light curing methods. The continuing increase in BisGMA released up to 72 hours indicates that this is most likely an insufficient time for the release of BisGMA into methanol and that more than 72 hours is required for the majority of BisGMA to elute.

TEGDMA was found to elute into methanol more rapidly than BisGMA. With standard QTH lights (Group I), 92% of TEGDMA had eluted over the first 9 hours; whereas, only 57% of BisGMA had eluted. At 24 hours, elution rates were 95% for TEGDMA and 78% for BisGMA.

According to the Stokes-Einstein equation $D= kT/6\pi\eta\alpha$ (where k=Boltzman constant, T=Absolute temperature, η=Absolute viscosity, α=Molecule radius), diffusion constant decreases with increasing radius size (Atkins, 1988). This is in accordance with Fick's laws for diffusion (Atkins, 1988), which supports reliability of the current results. In this study, while there were increases in elution over time for BisGMA, the smaller TEGDMA molecules were, by comparison, released at a faster rate (Atkins, 1988; Geurtsen & Leyhausen, 2001; Yap & others, 2004). BisGMA is comprised of two phenyl groups, making it a three-dimensional molecule. This, coupled with the fact that the molecular weight of TEGDMA is about half that of BisGMA, suggests that TEGDMA is more reactive than BisGMA in the polymer network (Tarumi & others, 1999). The smaller, lighter TEGDMA molecules are, therefore, eluted at a faster rate than the larger, heavier BisGMA molecules (Yap & others, 2004). In Group I, while 98% of TEGDMA had eluted into methanol at 48 hours, only 85% of BisGMA had eluted at 72 hours. This finding corroborates that of Yap and others (2004), who found that the majority of unreacted monomers present in BisGMA-TEGDMA composites were diluent TEGDMA molecules. Further studies are required to evaluate the rates of elution of monomers over extended time periods from various resin composites polymerized using different curing methods.

CONCLUSIONS

Under the conditions of this study, standard QTH curing appeared to result in higher levels of TEGDMA elution from the cured surface layer of resin composites than from high-intensity QTH fast-curing and standard LED curing. In the first six hours following polymerization, TEGDMA elution rates varied according to light curing mode. Regardless of curing mode, the majority of TEGDMA monomers were eluted into methanol by nine hours. No significant differences were observed between composites polymerized using different curing protocols in terms of BisGMA elution over set intervals of up to 72 hours, which appeared to be too short for complete elution of BisGMA into methanol.

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