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Effects of curing units and staining solutions on the color susceptibility of a microhybrid composite resin

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Abstract   *Background/purpose:* To examine the effect of different light-curing units and staining solutions on a microhybrid composite resin.
Materials and methods: Two shades (A3 and B3) of a light-activated composite (Ecusit resin) were cured in polytetrafluoroethylene disk rings (45 each) using 3 different light-curing units: 1) a quartz—tungsten—halogen (QTH) unit, 2) a light-emitting diode (LED) unit, and 3) a plasma-arc curing (PAC) unit. Two beverages (coffee and tea) were used as staining solutions, and distilled water was used as a control. Evaluations were made after 1, 7, 15, and 30 days by means of reflectance spectrophotometry.
Results: Data were statistically analyzed using one-way analysis of variance, and post-hoc comparisons were made using Tukey's test with a significance level of 5%. A Kruskal—Wallis multiple-comparison test was performed to evaluate ΔE^* values among water, tea, and coffee immersion with 2 shades of the composite. Statistically significant color changes were observed between water and coffee, and tea and coffee for different time periods; whereas no difference was seen between water and tea in LED-cured A3 Ecusit resin specimens after either 1 or 15 days of immersion, those cured by PAC after 15 days of immersion, or in LED-cured B3 Ecusit resin specimens after 7 days.
Conclusions: PAC-cured Ecusit resin specimens showed significantly higher discoloration than the other specimens. The staining solutions produced discoloration, while water caused the least changes.
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Introduction

Low cost and good aesthetics make composite resins widely accepted for restorative dental care.[1] Unfortunately, in addition to secondary caries, discoloration is one of the main reasons for removing resin composite restorations. Microhybrid composite resins are an improvement over traditional composite materials. Nowadays, universal microhybrid materials, indicated for anterior and posterior restorations, represent most resin-based composites on the market because of better aesthetics, smoother surfaces after polishing, and greater wear resistance.[2] Microhybrid composites contain irregularly shaped glass or quartz particles of fairly uniform diameters.

They usually have a distribution of 2 or more sizes of fine particles with average diameters of $0.4-3$ μm plus a microfine filler $0.04-0.2$ μm in diameter $(5-15\%)$. They contain $60-70\%$ filler by volume, which corresponds to $77-84\%$ by weight.[3] Although light-cured composites are excellent for esthetic procedures, both the physical and chemical properties of filled composites are directly related to the conversion of monomers to polymers. Low conversion rates lead to degradation, substance loss, fracture, and marginal breakdown, thus limiting the lifespan of the composite. Adequate polymerization of composite restorative materials is fundamental for obtaining optimal physical and chemical properties, and for achieving ideal clinical performance. At present, the following 3 major technologies for curing resin are used in dental practice: quartz−tungsten halogen (QTH) lamps, light-emitting diode (LED) lamps, and plasma arc (PAC) lamps.

QTH curing units are the most common means of curing dental composites.[1] Although they are cost effective, their intensity decreases over time, shortening their working life $(40-100$ h only) and necessitating frequent replacement of the light source to ensure efficient curing within the recommended time.[4,5] Moreover, the light energy generated is only 1% of the electric energy consumed, the remainder of which gets wasted as heat. Hence cooling fans are required, and this compromises the sterility of the handpiece. It is also essential to have a special filter to narrow down the visible spectrum to limit the wavelength to $370-550$ nm. PAC curing lamps were introduced with the advantage of shorter curing times. However, they suffer from the same disadvantages as QTH lamps.[6] Solid-state LED curing lights represent state-of-the-art technology in polymerizing composites. The semiconductor (gallium nitride) used is responsible for the blue light and the high efficacy of LEDs for dental applications.[7] LEDs operate at a wavelength of around 470 nm and a bandwidth of about 20 nm, and therefore have the spectral purity required for highly efficient curing of dental resins. Another advantage of LEDs is that the most common initiator of the polymerization reaction, diketone camphorquinone, has maximal absorption at 470 nm.[8]

New-generation LED curing lights are lightweight, portable, and highly efficient, and have long lifespans. Since a narrow band of light is emitted, there is no need for filter systems. Because there is no infrared emission, the curing lights have low amounts of wasted energy, leading to minimal heat generation, thus obviating the need for cooling fans. The LED curing light's power consumption is low, so batteries can be used to power it. The light output is consistent, there is no bulb to change, and the service life is long.[9] The only disadvantage is that LEDs can only polymerize materials with an absorption spectrum of $430-480$ nm (using camphorquinone as a photo-initiator) because of the narrow emission spectrum.

Monte Alto et al.[10] concluded that the energy density (t $(s) \times mW/cm^2 = J/cm^2$) is the most important factor in the effective polymerization of light-cured composites. Ceballos et al.[11] stated that the depth of cure and microhardness were not affected by the curing light used (QTH or LED). However, microhardness results were significantly affected by the interaction between the light curing source and exposure time and also by the interaction between the light curing source and depth.

Color stability is an important property of composites used in esthetic restorations, and several factors are associated with alterations of this property, such as the composition of the resin matrix and type of light curing unit used.[12] Another important component that interferes with this property is the photo-initiator system, that is responsible for yellow-shifts taking place over time.[13]

Coffee and tea, the two most common beverages, are consumed many times daily throughout the world, and a large amount of evidence implicates them in the staining of oral tissues, teeth, and prostheses. Therefore, it is necessary to investigate the potential risk that the consumption of these beverages poses to composite resins as they age. Although many studies separately evaluated the influence of different beverages[14] and staining solutions[15] on color change, surface characteristics, and microhardness of esthetic restorative materials, and the effect of different light-curing units on the properties of these composite resins, under clinical situations, both these factors work collectively to cause the net resultant discoloration. Moreover, the efficacy of PAC curing lights needs to be evaluated in terms of color stability. Therefore, this study was designed to investigate the effects of different light-curing units on the discoloration of a composite resin subjected to two popular and universally used staining solutions.

The purpose of this study was to determine, *in vitro*, whether there is any difference in the susceptibility to discoloration of different shades of microhybrid composite resin polymerized using three different light-curing units on exposure to two common beverages (tea and coffee).

Materials and methods

Two different shades (A3 and B3) of a light-activated syringable microhybrid composite resin (Ecusit, DMG, Hamburg, Germany) with a filler content (77% by weight and $0.02-1.5$ μm in size) were used.

Forty-five disk-shaped specimens of each shade (10 mm in diameter and 2 mm thick) were prepared in accordance with the manufacturer's instructions and by using a polytetrafluoroethylene ring covered with a celluloid matrix on one side and a glass slide on the other to create uniformly smooth finished surfaces.

Specimens were randomly divided into 3 groups according to the curing unit used: group I; specimens ($n = 15$) were cured with a QTH light (Litex™, Dentamerica, CA, USA) in standard mode with an intensity of 541 mW/cm^2 for 40 s; group II specimens ($n = 15$) were cured with an LED unit (Elipar FreeLight 2, 3M ESPE, St. Paul, MN, USA) in standard mode with an intensity of 800 mW/cm^2 for 40 s; and group III specimens ($n = 15$) were cured with a PAC lamp (1000 PAC, American Dental Technologies Inc, Southfield, USA) in standard mode with an intensity of 980 mW/cm^2 for 10 s. Light intensities were measured using a radiometer (model 100, Demetron Research, Danbury, CT, USA). The radiometer has calibrations for intensity measurement of 0–2000 mW/cm^2.

After fabrication of the specimens, the plastic strips and glass slides were removed. After the resin discs were ready, they were removed from the molds. Specimens were stored in a dark environment in a 37 °C incubator before testing. No polishing was attempted.

To prepare the coffee solution, 15 g of coffee powder (Nescafe Classic, Nestle Hellas, Athens, Greece) was poured into 500 mL of boiling distilled water. After 10 min of stirring, the solution was filtered through filter paper. The tea solution was prepared by immersing 5 prefabricated doses of tea powder (Golden Sun, Eswaran Brothers, Colombo, Sri Lanka) into 500 mL of boiling distilled water for 10 min. The two staining solutions were stored in separate vials and maintained at the oral cavity temperature (37 °C).

Color measurements

The color of the specimens was measured before immersion (baseline) by using a spectrophotometer (Color-Eye 7000, Gretag Macbeth, New Windsor, NY, USA). This instrument compares the amount of light that illuminates an object with the amount of light that is reflected. The spectrophotometer was calibrated with white and black ceramic tiles provided by the manufacturer. After making baseline color measurements, 5 randomly selected specimens from each group (groups I, II, and III) were immersed in one of the 2 staining solutions (experiment) or distilled water (control) at 37 ± 1 °C for 30 days. Color measurements were again recorded after 1, 7, 15, and 30 days. Before each measurement, specimens were gently washed in distilled water for 5 min and dried with tissue paper. The color change of each specimen was recorded. Values were recorded using the CIE LAB color system. The CIE LAB system is an approximately uniform color space with coordinates for lightness, namely, white–black (L∗), redness–greenness (a∗), and yellowness–blueness (b∗). The L∗, a∗ and b∗ values of each specimen were measured 3 times by a spectrophotometer at each experimental time period as described previously, and the mean values of the L∗, a∗, and b∗ data were calculated. The color difference (ΔE∗) was calculated from the mean ΔL∗, Δa∗ and Δb∗ values for each specimen using the formula:

$$\Delta E^* = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right]^{0.5};$$

where ΔL∗, Δa∗ and Δb∗ are the differences in the L∗, a∗ and b∗ values before (T0) and after immersion for each time interval.

Statistical analysis

For each time period, the ΔE means were subjected to a one-way analysis of variance using the Kruskal–Wallis test, and post-hoc comparisons were made using Tukey's test with a 5% significance level. The means were compared in terms of the tested curing source and the composite shade subjected to the staining agents, and the possibility of interactions between the 2 factors was included. The statistical software, SPSS for Windows (vers. 16, Chicago, IL, USA), was used for the analysis. Interpretation of the results was based on data that ΔE values of >3.3 were considered to produce visually unacceptable discoloration.[16]

Results

Table 1 presents the means and standard deviations of the color change values (ΔE∗) of the Ecusit resin (A3 and B3 shades). With the A3 shade, only specimens cured using QTH and immersed in the staining solutions showed significant color changes on day 7, while the other specimens immersed in water remained clinically acceptable during the same period. LED-cured samples showed relative stability on day 1 irrespective of the immersion solution. PAC-cured specimens showed maximum discoloration after immersion in either of the 2 staining solutions. In 7 days, all specimens, except those cured using LED, demonstrated unacceptable discoloration irrespective of the curing unit or staining solution. QTH- and PAC-cured samples showed ΔE changes at 15 days in both staining solutions, whereas LED-cured samples showed similar ΔE values only when immersed in tea. All specimens immersed in the staining solutions showed remarkable discoloration after 30 days, and the highest ΔE value was recorded for specimens cured with PAC (ΔE = 12.667 ± 1.71) and immersed in coffee, while the least affected were LED-cured (ΔE = 3.678 ± 0.31) specimens immersed in tea. The specimens immersed in water (controls) showed the least color changes throughout the experiment period when either QTH or LED units were used for curing. However, the PAC-cured samples showed the greatest discoloration when immersed in water at the 7-, 15-, and 30-day observations (Fig. 1).

With the B3 shade, all specimens appeared to exhibit good color stability after 1 day of immersion, except for those specimens cured with a PAC unit and immersed in coffee. Unacceptable color changes were noted in all 7- and 15-day samples immersed in coffee when LED or PAC units were used for curing. The 30-day immersion period produced unacceptable color changes in QTH- and PAC-cured specimens in both staining solutions. PAC-cured specimens were susceptible to the greatest amounts of color change when immersed in coffee and tea; while water seemed to produce significant discoloration but which was within the acceptable range (ΔE < 3.3) (Fig. 2).

Both shades (A3 and B3) of Ecusit resin cured using QTH, LED, and PAC showed statistically significant color changes (ΔE) when immersed in either of the staining solutions compared with water immersion at all time points (Table 2). On the other hand, there was no significant

Table 1 Mean (standard deviation) of the color change value (ΔE^*).

Resin composite	Curing unit	Immersion period (day)	Staining solution		
			Water	Coffee	Tea
Ecusit resin (A3)	QTH	1	0.514 (0.01)	2.658 (0.12)[a]	1.331 (0.12)[a]
		7	1.537 (0.12)	3.695 (0.46)[*b]	3.894 (0.12)[*b]
		15	2.026 (0.14)	5.222 (0.35)[*c]	4.542 (0.21)[*c]
		30	2.866 (0.21)	5.800 (0.32)[*d]	5.208 (0.23)[*d]
	LED	1	0.917 (0.03)	1.553 (0.10)[a]	0.796 (0.02)[a]
		7	1.815 (0.15)	3.046 (0.43)[b]	2.230 (0.22)[b]
		15	2.425 (0.32)	4.481 (0.42)[*c]	2.790 (0.23)[c]
		30	2.291 (0.30)	5.574 (0.26)[*]	3.678 (0.31)[*d]
	PAC	1	1.117 (0.11)	5.502 (0.40)[*a]	4.582 (0.31)[*a]
		7	3.714 (0.52)[*]	10.122 (2.12)[*b]	4.686 (1.12)[*b]
		15	4.810 (1.04)[*]	12.206 (2.67)[*c]	5.251 (1.04)[*c]
		30	4.367 (0.56)[*]	12.667 (1.71)[*d]	5.002 (0.81)[*]
Ecusit resin (B3)	QTH	1	0.178 (0.01)	2.085 (0.31)[A]	0.960 (0.05)[A]
		7	1.167 (0.09)	3.099 (0.31)[B]	1.349 (0.21)
		15	1.627 (0.13)	4.333 (0.20)[*]	2.728 (0.70)[C]
		30	2.478 (0.31)	6.706 (0.41)[*D]	3.953 (0.12)[*D]
	LED	1	0.467 (0.02)	2.952 (0.11)[A]	1.306 (0.03)[A]
		7	1.335 (0.11)	3.993 (0.40)[*B]	1.724 (0.04)[B]
		15	1.948 (0.14)	4.461 (0.46)[*C]	2.620 (0.23)
		30	1.782 (0.16)	4.765 (0.50)[*D]	2.783 (0.13)[D]
	PAC	1	0.978 (0.04)	4.678 (0.25)[*A]	3.052 (0.13)[A]
		7	2.883 (0.51)	11.422 (2.10)[*B]	3.548 (0.43)[*B]
		15	3.188 (0.31)	12.256 (1.41)[*C]	5.033 (1.01)[*C]
		30	3.109 (0.51)	12.571 (2.01)[*D]	4.836 (0.63)[*D]

* Indicates clinically perceptible values ($\Delta E^* > 3.3$).
Similar superscript letters (a or A, b or B, c or C, d or D) in the coffee and tea columns, indicate significant differences among QTH, LED, and PAC in the same column. For example, in the coffee column, [a] appears in the first, fifth, and ninth cells, indicating statistical significant differences among the QTH, LED, and PAC groups at 1 day for the Ecusit resin (A3) ($P < 0.05$). In the same vein, the superscript [A] appears in cells 13, 17, and 21 (of the coffee column) indicating statistically significant differences for the 3 curing methods using the Ecusit resin (B3).
QTH, quartz–tungsten–halogen; LED, light-emitting diode; PAC, plasma arc.

difference when comparing between water and tea immersion of A3 specimens cured by LED after 1 and 15 days, in A3 specimens cured by PAC after 15 days, and in B3 specimens cured by QTH or LED after 7 days.

Discussion

There are 2 major aspects relating to color changes of composite restorations that need to be considered. One is the actual change in the appearance of the material that spontaneously occurs over time because of several factors, and the other is the perception of color change that makes it unacceptable. The discoloration of resin-based composite systems appears to be related to multiple factors.[17] Essentially, it can be sorted into 3 broad categories (in descending order of importance): the properties of the restorative material used, the clinical conditions, and the bioenvironment in which the restoration is placed. The first can be further analyzed on the basis of the composition of the composite material,[3,18] its degree of polymerization,[19,20] its physical stability (resistance to volumetric shrinkage and surface characteristics), chemical stability (resistance to photo-oxidation and sorption),[21] and

its biological stability (resistance to both absorption and adsorption of staining substances).[22] Variable clinical parameters include the source of the curing light,[23,24] curing mode,[25] curing time,[1] the distance between the light source and resin surface,[26] and the surface characteristics of the resin.[27]

The present study was principally designed to evaluate the influence of light-curing units on the susceptibility of 2 shades of a microhybrid composite resin to 2 staining solutions. The composite was fabricated in close contact with a glass plate to spontaneously and consistently produce a smooth surface, thus abolishing any need for polishing. Two shades of the same composite material were selected so that compositional variance did not exist. The specimens were made using a 2-mm-thick polytetrafluoroethylene ring, and the curing lights were held in contact with the surface, hence establishing uniformity in the depth of cure. In this way, some of the potential risk factors for color instability, such as surface irregularities, composition of the resin, distance between the light source and resin surface, and depth of cure, were eliminated. Color perception by visual assessment of objects is a subjective, physiological and psychological process that varies between and within persons. To exclude any possible observer-related error,
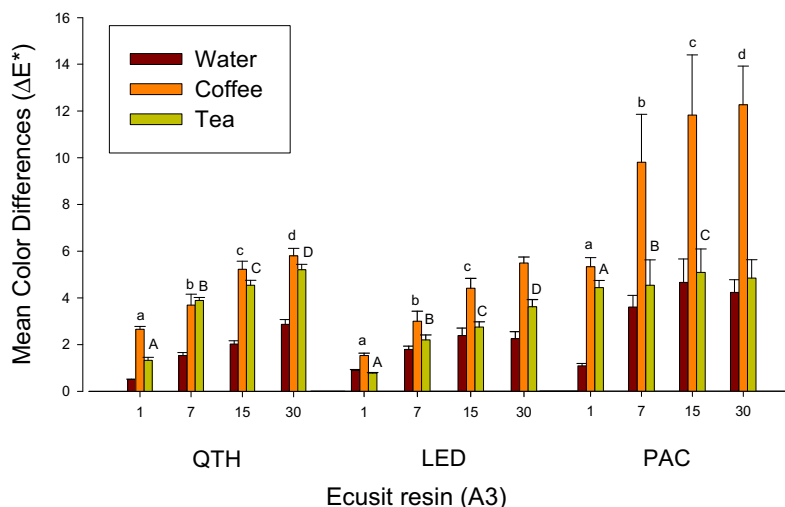
The similar letters at the top of the coffee and tea bars for same day, indicate a statistically significant difference (P<0.05).

Figure 1   Mean color differences (ΔE∗) after 1, 7, 15, and 30 d of exposure to coffee, tea, and water for the 3 curing methods using Ecusit resin (A3). QTH, quartz-tungsten-halogen; LED, light-emitting diode; PAC, plasma arc.

the color change in the specimens was measured using a spectrophotometer.[28,29] The 2 staining solutions were maintained at 37 °C to simulate the oral cavity temperature and hence eliminate any alterations in the properties or potency of the staining solutions because of temperature variations.[30]

The quantitative assessment of minimal color changes and differences exclusively by a visual examination is not useful or even possible. The results may be subjectively linked to an examiner's opinion and thus have low reproducibility.[28] Reproducible, objective, and statistically usable color measurements can only be achieved with standardized color-quantifying devices. Hence a spectrophotometer is routinely used to assess color behaviors of different dental restorative materials.[31—33]

The value of ΔE∗ represents relative color changes that an observer might report for a material after treatment or

between time periods. A ΔE∗ value of >3.3 was accepted by most authors[16,34] to produce visually unacceptable discoloration and so was used as the standard in our study. It is also important to emphasize the impossibility of establishing an exact correlation between *in vitro* and *in vivo* tests, since the oral environment cannot be reproduced in the laboratory, and restorative materials are never subjected to staining media for such a long period of time.[35] In this study, specimens cured with PAC and immersed in coffee showed the highest value (ΔE = 12.667 ± 1.71), whereas the least affected were LED-cured (ΔE = 3.678 ± 0.31) specimens immersed in tea. On the other hand, specimens immersed in water showed clinically acceptable ΔE values (ΔE < 3.3).

Considering the staining solutions, our results show that the coffee solution produced unacceptable discoloration of QTH-cured A3 shade specimens even at 7 days of
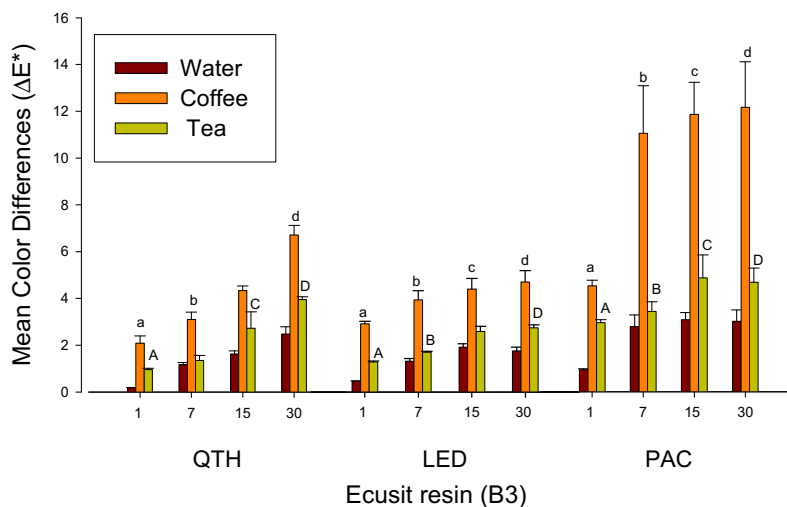
The similar letters at the top of the coffee and tea bars for same day, indicate a statistically significant difference (P<0.05).

Figure 2   Mean color differences (ΔE∗) after 1, 7, 15, and 30 d of exposure to coffee, tea, and water for the 3 curing methods using Ecusit resin (B3). QTH, quartz-tungsten-halogen; LED, light-emitting diode; PAC, plasma arc.

Table 2 Kruskal–Wallis multiple-comparison test results for ΔE* in terms of staining solutions.

Immersion period (d)	Staining solution	Ecusit resin (A3)			Ecusit resin (B3)		
		QTH	LED	PAC	QTH	LED	PAC
1	Water–tea	+	−	+	+	+	+
	Water–coffee	+	+	+	+	+	+
	Tea–coffee	+	+	+	+	+	+
7	Water–tea	+	+	+	−	−	+
	Water–coffee	+	+	+	+	+	+
	Tea–coffee	+	+	+	+	+	+
15	Water–tea	+	−	−	+	+	+
	Water–coffee	+	+	+	+	+	+
	Tea–coffee	+	+	+	+	+	+
30	Water–tea	+	+	+	+	+	+
	Water–coffee	+	+	+	+	+	+
	Tea–coffee	+	+	+	+	+	+

+, Indicates a statistically significant difference ($P < 0.05$); −, indicates no statistically significant difference ($P > 0.05$).
QTH, quartz–tungsten–halogen; LED, light-emitting diode; PAC, plasma arc.

immersion, and at 15 days immersion, unacceptable discoloration of LED-cured specimens was noted; PAC-cured specimens attained saturation at as early as 1 day. Only the LED-cured A3 resin exhibited a marked degree of resistance to unacceptable color change when immersed in a tea solution for 30 days. QTH- and PAC-cured A3 specimens suffered significant and unacceptable color changes. PAC-cured A3 samples attained saturation at as early as 1 day and henceforth maintained the color, making the resin unacceptable even after 1 day of immersion.

A3 specimens appeared to be more susceptible to discoloration when immersed in the tea solution compared with B3 when QTH or LED units were used for curing. This result is in contrast to observations of Pires-de-Souza et al.[24] who demonstrated that the A3 hybrid composite showed greater color stability regardless of the light-curing unit. But when these 2 shades were immersed in the coffee solution, they exhibited unacceptable color changes from 7 days onwards. Both A3 and B3 specimens cured using QTH exhibited relatively comparable and unacceptable discoloration on immersion in the coffee solution for all periods over 7 days. These findings indicate that both A3 and B3 were more highly stained in the coffee solution, correlating well with findings of Scott et al.[36] and Yannikakis et al.[33] The major cause of discoloration because of staining solutions is extrinsic adsorption and absorption of pigments into the subsurface, but intrinsic discoloration may also exist.[40] Coffee pigmentation originates from both mechanisms of adsorption of colorant on the surface and absorption in the subsurface layer,[19] but discoloration is probably related to the compatibility of the polymeric phase of the composite resin. Such resin discoloration may be associated with its affinity for stains and water sorption because of its lower degree of monomer conversion.[19]

It was interesting to observe that LED-cured A3 and B3 samples showed remarkable resistance to discoloration on immersion in tea for all time periods, whereas the coffee solution produced unacceptable discoloration in both shades at all periods exceeding 7 days. The efficiency of polymerization may influence discoloration, since the

higher the degree of conversion, the smaller the amount of residual monomers available to form colored degraded products.

Several studies documented the effectiveness of LED light for curing composite resins. Early LED lights introduced into the market were not as powerful as standard QTH lights. But Burgess[6] cited that the performance of 2nd-generation LED lights (FreeLight 2 at 800 mW/cm^2) was much better than either of the low-power-density first-generation LED lights (Elipar FreeLight at 279 mW/cm^2). Yoon et al.[23] demonstrated that the LED conversion performance did not significantly differ from that of a halogen light when the total energy was set to 16 J/cm^2 for both lights,[37] and the conventional QTH light and a similar-intensity LED was used in our study. Vandewalle et al.[38] claimed that high-powered LED lights provided conversion ratios similar to or better than halogen curing lights at curing distance of 5 mm, and since the curing source was held in close contact with the resin in our experiment, this could be a possible explanation for the relatively good color stability exhibited by the LED-cured specimens against discoloration and aging.

Pires-de-Souza et al.[24] found no statistically significant difference between the efficiencies of QTH- and LED-curing units on the color stability of 3 composite resins of 2 different shades (A3 and C3). Our results agree with the conclusions of Yazici et al.[39] who investigated the effects of QTH- and LED-curing units and 2 staining solutions (tea and coffee) on the color stability of a hybrid composite and a nanohybrid composite after different immersion periods. They found that the effect of the staining solutions on color changes in composites was dependent on both the immersion time and resin material.

Peutzfeldt et al.[40] achieved comparable polymerization characteristics of resin composites with a PAC 1000 unit for 10 s and with 20 or 40 s curing with a conventional curing unit. But unfortunately, the PAC-cured A3 resin showed unacceptable discoloration irrespective of the immersion solution and even with water immersion, while both shades cured using PAC experienced maximum discoloration after

immersion in a coffee solution. Unacceptable discoloration occurred even in water after 7 days. With coffee immersion, it occurred even earlier (in 1 day), and a dramatic amount of color change was observed at 7 days, which reached saturation thereafter, similar to the findings of Um and Ruyter[34] and Wiltshire and Labuschagne.[35] PAC-cured A3 specimens showed discoloration on tea immersion, and even that appeared to reach saturation after 1 day, and remained the same throughout the experimental period. B3 showed unacceptable color change at 7 days. These findings can be attributed to the fact that the PAC-curing unit possesses the inherent property of rapid curing. This may result in the formation of short polymer chains, as the faster rate of cure might not allow sufficient time for the pre-gel phase of the material to absorb the polymerization/contraction stresses.[41] Deb and Sehmi[42] also demonstrated that the PAC light led to inefficient curing that caused higher than usual levels of residual free monomer to remain and greater shrinkage compared with curing with a halogen light. A high degree of conversion not only gives hardness and strength to a material,[20] but also responsible for color stability.[17] Thus, a reduction in the remaining double bonds to the lowest possible level is normally considered a desirable feature of a polymerization system. The degree of conversion of a given resin composite is influenced by the energy density. Yet another explanation for the greater undesirable color change of PAC-cured specimens (both A3 and B3) could be the high susceptibility to water sorption at the resin-filler interface. Color perception is directly connected to light scattering by particles in the composite resin and interfaces among them. This is one of the well-documented weak points of composite materials.[43]

In conclusion, coffee- and tea-stained PAC-cured specimens showed significantly more discoloration than QTH- and LED-cured specimens. LED-cured specimens were more resistant to discoloration over a longer immersion period compared with the other 2 curing modes. Furthermore, the coffee solution caused the highest staining among the storage solutions tested.

Acknowledgments

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