Effect of Light-Curing Distances on the Color and Translucency of Resin Composites After Accelerated Aging

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Polymerization plays an important role in the color and translucency of resin composite materials. The aim of this study was to evaluate the effect of light-curing distances of resin composites on color change (ΔE_{00}) and translucency change (ΔTP) after accelerated aging (AA). Four resin composites (G-Aenial Anterior, Charisma Smart, GrandioSO, and Admira Fusion) were used. The resin composites were cured from 0 mm, 2 mm, and 4 mm distances. A spectrophotometer was used to determine the color measurements and calculate the color change and translucency using the CIEDE2000 formula. The resin composites were submitted to AA for 300 h. Two-way analysis of variance and multiple comparisons Tukey's test were used ($p < 0.05$). ΔE_{00} at 0 mm and 2 mm distance was similar, but higher was found at 4 mm distance. The highest and lowest ΔE_{00} were observed in the G-Aenial Anterior and Charisma Smart respectively. But no differences were observed between Charisma Smart and Admira Fusion. Translucency changes at 2 mm and 4 mm distances were similar, but lower translucency changes were observed at a distance of 0 mm. The translucency change values of the materials were found to be similar after accelerated aging. Increasing the light-curing distance can lead to deterioration of color stability and a tendency to decrease translucency. Clinicians should position the light-curing device as close to the material as possible.

Keywords: artificial accelerated aging, color change, polymerization, resin composites, translucency.

1. INTRODUCTION

Tooth-colored resin composite material should imitate the optical properties, shape, and surface textures of natural teeth [1] and provide excellent aesthetics [2]. With the advances in nanotechnology, resin composites applied in the restoration of anterior and posterior teeth have been developed [3]. These materials are two main components disperse phase (inorganic) and the resin matrix phase (organic). Moreover, they include additional structures, such as photoinitiator, accelerator, and pigment. However, some of these structures may deteriorate over time and as a result influence the optical properties of resin composite [4]. In addition, inadequate polymerization of these materials may cause problems, such as color changes, pulpal irritations, postoperative sensitivity, and restoration failures [5]. The color change can be affected by intrinsic (chemical changes, degree of polymerization, inorganic content, inhibitor, activator, and amine type in the resin) [1] and extrinsic (insufficient polymerization intensity and time, temperature, and food colorants) factors [2]. Resin composite materials may have a tendency to stain during prolonged service [6]. However, discoloration of restorations requires the replacement of the restorations [4]. Therefore, the color change of composites should be ensured and the material color is expected to remain constant in the long term [5]. Resin composites must be photopolymerized under ideal conditions for clinical service. The light-curing process should be placed perpendicular to the restoration and as close as possible to ensure a homogeneous light beam. The height of the posterior tubercle, the use of matrix, and the shape or size of the curing device, combined with limitations in mouth opening, make effective polymerization difficult. Furthermore, it is necessary to keep the polymerization device close to the restoration [7]. In addition, clinicians are often unaware of the performance of light-curing devices, which can disrupt the polymerization mechanism of resin composites [3].

The color stability of aesthetic restorative material should not be affected by the polymerization or aging method [8]. The aging process can be used for short-term and long-term evaluations, which may cause deterioration and lead to changes in the optical properties of the materials. Due to the aging process, it can promote effects in the surface structure of resin composites, the chemical content of the resin matrix, and the particle of fillers [4]. The optical properties should be acceptable from different distances after polymerization. Therefore, the aim of our study was to evaluate the effect of light-curing distances (0 mm, 2 mm, and 4 mm) of resin composites on color and translucency changes after accelerated aging (AA). The null hypothesis of this study is that the main effects of distance, composite, and interaction of composite distance do not have a significant effect on color and translucency change.

2. EXPERIMENTAL DETAILS

According to the Vita Classical shade guide scale (Vita Zahnfabrik, Bad Säckingen, Germany) shade A2 of four different resin composites (G-Aenial Anterior, GC Corp. Tokyo, Japan; Charisma Smart, Kulzer GmbH, Hanau,

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Germany; GrandioSO, Voco, Cuxhaven, Germany; and Admira Fusion, Voco, Cuxhaven, Germany) were used (Table 1). A Teflon mold (8 mm diameter and 2 mm thickness) was used to prepare the disc-shaped specimens of the resin composites. The resin materials were placed into holes, and a Mylar strip was placed over the top surfaces. The resin composites were cured with a light-emitting diode (Woodpecker LED.E (P), Woodpeckers Med. Inst. Co., Guilin, China) curing light at 1200 mW/cm^2 for 40 s directly over Mylar strips from distances of 0 mm, 2 mm, and 4 mm. Thirty disc-shaped specimens were prepared for each composite group. All the specimens were stored at 37 °C for 24 h in distilled water.

2.1. Color change measurements

The initial color measurements were performed using a spectrophotometer (Lovibond RT Series, Tintometer Group, Lovibond House, UK) on a white background. The color differences were computed using the CIEDE2000(1:1:1) Eq. 1 [9, 10]:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L} \right)^2 + \left(\frac{\Delta C'}{K_C S_C} \right)^2 + \left(\frac{\Delta H'}{K_H S_H} \right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C} \right) \left(\frac{\Delta H'}{K_H S_H} \right) \right]^{\frac{1}{2}}, \quad (1)$$

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are the change in lightness, chroma, and hue, respectively, between two samples. The relationship between the variations of chroma and hue in the blue region is defined by the rotation function (R_T). The weighting functions of lightness, chroma, and hue are denoted by S_L, S_C, and S_H, respectively. K_L, K_C, and K_H are the parametric factors of set 1 in this study [11].

2.2. Translucency parameter (TP)

The initial color measurements were obtained using a spectrophotometer (Lovibond RT Series, Tintometer® Group, Lovibond House, UK) on a black and white backgrounds. TP_{00} was calculated using the CIEDE2000(1:1:1) color differences Eq. 2 [12]:

$$TP_{00} = \left[\left(\frac{L'_B - L'_W}{K_L S_L} \right)^2 + \left(\frac{C'_B - C'_W}{K_C S_C} \right)^2 + \left(\frac{H'_B - H'_W}{K_H S_H} \right)^2 + R_T \left(\frac{C'_B - C'_W}{K_C S_C} \right) \left(\frac{H'_B - H'_W}{K_H S_H} \right) \right]^{1/2}. \quad (2)$$

Subscripts "*B*" and "*W*" (specified in the formula) correspond to black and white backgrounds, respectively. ($L_B' - L_W'$), ($C_B' - C_W'$), and ($H_B' - H_W'$) denote the changes in lightness, chroma, and hue on black and white backgrounds, respectively. The relationship between the variations of chroma and hue in the blue region is defined by the rotation function (R_T). The weighting functions of lightness, chroma, and hue are denoted by S_L, S_C, and S_H, respectively. K_L, K_C, and K_H are the parametric factors set 1 in this study [12].

After initial measurements, all specimens were aged for 300 h and 150 kJ/m^2 in an accelerated aging chamber (Atlas ci 4000; Atlas Electronic Devices Co., Mount Prospect, Il, USA) [13]. The aging procedure was performed as stated in the previous study [14]. The aging process was as follows: 60 minutes in the dark with back water spray; 40 minutes under illumination; 20 minutes under illumination water spray; and 60 minutes under illumination. The temperature of the back panel was maintained at 38 ± 2 °C in the dark and 70 ± 3 °C under illumination. The dry-bulb temperature was 38 ± 2 °C in the dark and 47 ± 3 °C under illumination. Relative humidity was maintained at 95 ± 5 % in the dark and 50 ± 5 % under illumination. After the AA procedure, the procedures for measuring color change, *TP*, and hardness were repeated.

Table 1. List of materials used in the present study

Composite (A2) Material/Manufacturer	Composite Type*	Component	Inorganic filler concentration: weight % – volume %	Lot
G-Aenial Anterior (GC Corp, Tokyo, Japan)	Micro-hybrid composite	Resin matrix: UDMA, dimetacrilat co-monomers Filler: pre-polymerise organic filler, silica, strontium, lanthanoid florid, fumed silica (0.1 – 17 µm)	76 % – 63 %	190603B
Charisma Smart (Kulzer GmbH, Hanau, Germany)	Submicron-hybrid composite	Resin matrix: Bis-EMA, HEDMA, TEGDMA Filler: barium aluminum fluoride glass filler of 0.02 – 2 µm, pyrogenic silicon dioxide filler of 0.02 – 0.07 µm	78 % – 63 %	K010517
GrandioSO (Voco,, Cuxhaven, Germany)	Nano-hybrid composite	Resin matrix: Bis-GMA, Bis-EMA, TEGDMA Filler: 0.5 – 10 µm particles; 20 nm particles, glass ceramic fillers, functionalised SiO_2	89 % – 73 %	1919203
Admira Fusion (Voco, Cuxhaven, Germany)	Nano-hybrid ormocer composite	Resin matrix:Ormocer Filler:silicon oxide nano filler, glass ceramics filler (1 µm)	84 % – 69 %	1919555

Bis-GMA: bisphenol A glycol dimethacrylate; Bis-EMA: bisphenol A ethoxylated dimethacrylate; TEGDMA: triethylene glycol dimethacrylate, UDMA: urethane dimethacrylate; HEDMA: 1,6-hexanediylbismethacrylate
*The data regarding the type of resin composites were obtained from the manufacturers

2.3. Statistical analyses

Statistical analyses were performed using SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, USA). The data were checked for normal distribution (Kolmogorov-Smirnov test), and homogeneity (Levene Test). Tukey's test for post hoc analysis was used for multiple comparisons. Color change and translucency change were considered as dependent variables within the model. The ΔE_{00} and ΔTP data were analyzed using two-way analysis of variance (two-way ANOVA). It was tested whether the color change or translucency change after aging differs according to the effect of composite, distance and interaction of composite distance. Partial eta squared (η^2) values are a statistical measure used to rank the effect of independent variables on dependent variables. The effect of composite, distance, composite and distance combinations on the dependent variable was also shown with partial eta squared (effect size). It was used to show the level of the main effect or the effect of the interaction on the dependent variable. If the interaction between distance and composite was not significant, the color change or translucency change values of the analyzed variables on the main effects were evaluated by examining the total values (if the main effect was significant), and the significances were shown in the tables. The significance level was determined to be $p < 0.05$.

3. RESULTS AND DISCUSSION

The two-way ANOVA results of the main effects and interactions between distance and composite on color change are shown in Table 2. No significant difference was found between distance and composite interaction ($p = 0.394$).

The main effect of independent variables (distance, composite) on the color change values was significant (p values 0.003 and < 001, respectively) (Table 2). The color change at 0 mm and 2 mm distance was similar, but a higher color change was found at 4 mm distance. Color changes differed significantly between the materials. The highest and lowest color changes were observed in the G-Aenial Anterior and Charisma Smart, respectively. No difference was observed between Charisma Smart and Admira Fusion (Table 3).

The interaction of distance and composite on translucency change is shown in Table 4. No significant difference was found between distance and composite interaction ($p = 0.846$). The main effect of the independent variable (distance) on the translucency change values was significant ($p = 0.041$) (Table 4). The main effect of the independent variable (composite) on the translucency change values was significant ($p = 0.409$) (Table 4).

Translucency changes at 2 mm and 4 mm distances were similar, but lower translucency changes were observed at 0 mm. While the translucency changes values of G-Aenial Anterior were observed as high, the translucency change values of Charisma Smart were observed as low. However, the translucency change did not differ significantly between the composite materials (Table 5).

The optical properties of the composite resins used for aesthetic restorations should not be affected by polymerization distance. In this study, the interaction of distances and composite types did not affect color and translucency changes. However, it exhibited a significantly high color change at a 4 mm light-curing distance (Table 3). A previous study reported acceptable perceptibility and acceptability thresholds of 0.81 and 1.77, respectively [10]. In our study, the tested resin composites generally showed above the perceptibility and acceptability thresholds (Fig. 1). However, Charisma Smart showed below acceptability thresholds of light-curing distances of 0 mm and 2 mm, and Admira Fusion showed acceptability thresholds of the light-curing distance of 0 mm. The color change of composite resins can vary depending on many factors, such as material content, resin matrix, filler composition, matrix-fill interface, degree of polymerization, finishing, and polishing methods [15].

Table 2. Two-way ANOVA results for color change main effects (composite, distance and interactions between composite and distance

Source	Type III	df	Mean square	F	Sig.	η^2 (effect size)
Distance	7.394	2	3.697	6.210	0.003	0.103
Composite	33.356	3	11.119	18.676	< 001	0.342
Distance * composite	3.772	6	0.629	1.056	0.394	0.055
R squared = .413 (adjusted *R* squared = .354) df: degree of freedom, F: Two-way analysis of variance test statistic						

Table 3. Means and standard deviations for ΔE_{00}**.** The total data in the column indicates the composites, and the total data in the row indicates the distances

	0 mm	2 mm	4 mm	Total
G-Aenial Anterior	2.99 ± 0.80	3.13 ± 0.44	3.17 ± 0.65	3.10 ± 0.63^{A}
Charisma Smart	1.39 ± 0.68	1.52 ± 0.58	2.42 ± 1.74	1.78 ± 1.18^{C}
GrandioSO	2.12 ± 0.39	2.15 ± 0.37	2.39 ± 0.43	2.22 ± 0.40^{B}
Admira Fusion	1.40 ± 0.85	1.88 ± 0.34	2.32 ± 0.67	$1.87 \pm 0.74^{B,C}$
Total	1.98 ± 0.95^{a}	2.18 ± 0.79^{a}	2.58 ± 1.03^{b}	2.25 ± 0.95
$^{A, B, C}$ represent statistically significant differences in each column $^{a, b}$ represent statistically significant differences in each row				

Table 4. Two-way ANOVA results for translucency change main effects (composite, distance) and interactions between composite and distance

Source	Type III	df	Mean square	F	Sig.	η^2 (effect size)
Distance	9.874	2	4.937	3.280	0.041	0.057
Composite	4.389	3	1.463	0.972	0.409	0.026
Distance * composite	4.037	6	0.673	0.447	0.846	0.024
R squared = .101 (Adjusted *R* squared = .010) df: degree of freedom, F: Two-way analysis of variance test statistic						

Table 5. Means and standard deviations for *TP* and *ΔTP* (baseline minus after accelerated aging) of the tested materials. *ΔTP* ($TP_B - TP_A$); the subscript B is related to *TP* value obtained at the before AA whereas the subscript A refers to *TP* after AA. The total data in the column indicates the composites, and the total data in the row indicates the distances

	0 mm	2 mm	4 mm	Total
G-Aenial Anterior	0.46 ± 1.24	1.25 ± 1.12	1.39 ± 1.50	1.03 ± 1.32
Charisma Smart	0.82 ± 1.21	0.90 ± 1.08	1.02 ± 2.12	0.91 ± 1.49
GrandioSO	0.33 ± 0.51	0.46 ± 0.79	0.77 ± 0.78	0.52 ± 0.70
Admira Fusion	0.18 ± 1.24	0.72 ± 1.28	1.42 ± 1.05	0.77 ± 1.26
Total	0.45 ± 1.08[a]	0.84 ± 1.08[a, b]	1.15 ± 1.42[b]	0.81 ± 1.23
[a, b] represent statistically significant differences in each row				

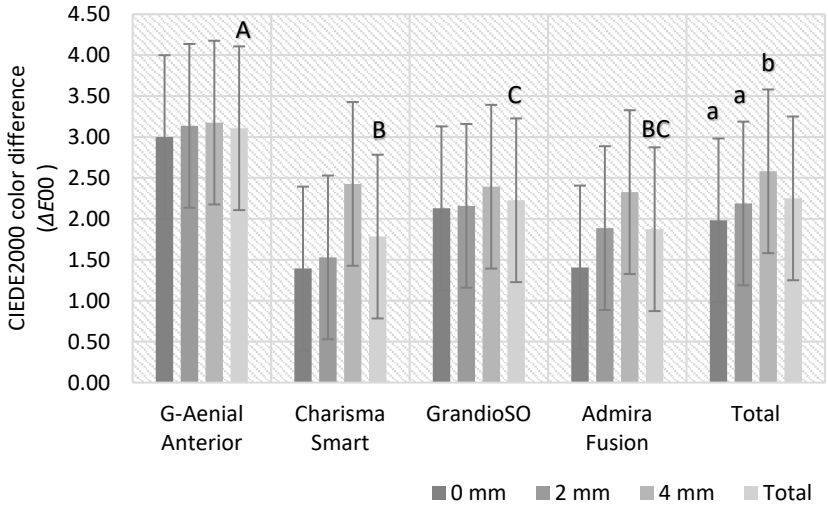

Fig. 1. Mean and standard deviation values for color change with different interactions of variables (composite, distance and composite-distance). Capital letters indicate the differences between the total color change values of each distance group. Lower letters indicate the differences between the total color change values of each composite group. There is no difference between the same letters

In this study, the samples were not polished, and a Mylar strip was used during light polymerization for standardization of the samples. The AA procedure imitates oral conditions, claiming that 300 h of weathering in a weather-O-meter equals 1 year of clinical service intraorally [16]. The AA imitates the effect of prolonged exposure to environmental factors, such as differences in light, temperature, and moisture [17]. For a color change; the main effect (partial eta squared) for the distance variable was $\eta^2 = 0.103$, while the main effect for the composite was $\eta^2 = 0.342$ (Table 2). The effect of the composite was obtained higher than that of the distance effect. These findings indicate that the composite resin content has a greater effect on color change and can be attributed to the material contents. Admira Fusion and Charisma Smart showed the lowest color change after AA. Celik et al. [8] reported that submicron-hybrid composites exhibited less color change than nano-hybrid composites. Charisma Smart contains Bis-EMA, HEDMA, TEGDMA, and barium aluminum fluoride glass filler and may be more resistant to color changes caused by AA due to its content. Admira Fusion contains ormocer and does not contain any other monomers. It contains inorganic-organic copolymers and inorganic silanated filler particles, which are stated as three-dimensionally cross-linked copolymers [18]. Khosravi et al. [19] reported that the color stability of the nano-filled resin composite is more resistant than the micro-hybrid composite. In our study, the G-Aenial Anterior showed the highest color change after AA. This microhybrid material contains UDMA (Bis-GMA-free). Previous research reported that this monomer prone to yellowing after AA [4]. This color change may have been more severe due to the larger particle size as well as the interaction of AA with the monomer structure in this material. However, a smaller fillers size does not necessarily equate to a low level of discoloration [20]. In aesthetic restorative materials, color changes are associated with matrix and filler compositions and contents, macroscopic phenomena, pigments, the

concentration or type of activator, initiator, inhibitor, and oxidation of unreacted carbon-carbon double bonds [8]. The degradation of residual amine and oxidation of residual unreacted carbon-carbon double bond result in the yellowing of resin materials [20]. Unreacted amine concentrations were not measured in the resins in this study, as the increased yellowing of nano-containing composites is presumed to be due to a lower degree of conversion or AA. Therefore, discoloration is related to many factors.

The *TP* of a material is defined by its difference in color on a black and white backgrounds [4]. The translucency of a material is related to the extent or abundance of absorption, light scattering, resin matrix, filler particle, and dye in the material [21]. Since accelerated aging influences the filler particles related to the reflection and transmission of light by changing the perception of translucency, it can be assumed that inter-material differences in translucency can be explained by differences in refractive index values [4]. In our study, the translucency values decreased the resin composites. However, there were no significant differences in *ΔTP* values among the tested composites (Table 5). This finding is similar to the results of the previous study's finding that AA did not affect *ΔTP* values [4]. For translucency change; the main effect (partial eta squared) for the distance variable was $\eta^2 = 0.057$, while the main effect for composite was $\eta^2 = 0.026$ (Table 4). The effect of distance was obtained higher than that of the composite effect. These findings indicate that the polymerization distance has a higher effect on the translucency change than the composite contents. The *ΔTP* was not significant between 0 mm and 2 mm, but a higher *ΔTP* was observed at 4 mm. The curing distance may have affected the degree of conversion in the materials. In this study, the G-Aenial Anterior with micro-hybrid content showed high *ΔTP* values. A decrease in the size of the filler particles was observed in hybrid composites containing microparticles, and light penetration decreased as the small particles emitted light [22]. GrandioSO with ormocer content showed low *ΔTP* values. However, no difference was observed between the translucency change values of the analyzed materials. After AA, a decrease in the translucency of the materials was observed. The high temperature during accelerated aging may have caused a change in the refractive index of the matrix, increasing the degree of transformation [15]. In our study, as a result of increased scattering, it made the material less translucent. Since AA affects the filler particle responsible for the reflection and transmission of light, altering the perception of translucency, it can be assumed that translucency is altered by changing the refractive index. In contrast with the results of a previous study, [23] in our study, composite resins did not show significant changes in translucency after AA.

Based on our results of this study, the effect of composite, distance, composite and distance combinations were evaluated and was also shown with effect size. Furthermore, the interaction of distances and composite types did not affect color and translucency changes. The aging procedure was applied to imitate the effects of prolonged exposure to oral conditions. The optical properties (color and translucency changes) of the materials after accelerated aging were evaluated in vitro. Patient habits and brushing, saliva in the mouth, temperature changes, and pH level can also affect the properties of resin composites. These factors can affect color difference values. The efficacy of different polymerization devices may be different; therefore, the optical properties of the materials may vary. However, this study suggests a trend that should be confirmed by future studies.

4. CONCLUSIONS

Within the limitations of this study, among the resin composites, increasing the light-curing distance can lead to deterioration of color stability and a tendency to decrease translucency. It was observed the micro-hybrid composite had a higher color change tendency and the submicron-hybrid composite preserved its color stability. Clinicians should position the light-curing device as close to the material as possible.

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