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Influence of Daylight Exposure on the Colour Stability and Staining Susceptibility of a Composite Resin

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ABSTRACT

Objectives: This study evaluated colour change of composite resin after daylight exposure, simulating scenarios where material remains in mixing plates with open light-blocking covers. The effect of polishing on colour recovery after coffee staining was also assessed.

Materials and Methods: Thirty-five disc-shaped nano-hybrid composite specimens (NeoSpectra ST, Dentsply Sirona) were randomly allocated into five groups (n = 7): negative control (no daylight exposure, no staining), positive control (0-minute daylight exposure with staining), and three experimental groups exposed to natural daylight for 2, 4, or 6 minutes before polymerization. After curing, specimens were polished with Sof-Lex discs (3M ESPE) from coarse to fine grit following manufacturer's instructions. Baseline colour measurements (T_0) were obtained using a spectrophotometer (VITA Easyshade V). Except for controls, specimens were immersed in coffee for 7 days and remeasured (T_1). After repolishing, measurements (T_2) were recorded. Colour differences were calculated using CIEDE2000 (ΔE_{00}) formula for staining (T_0–T_1), polishing (T_1–T_2), and total change (T_0–T_2). Data were analysed with repeated-measures ANOVA and Bonferroni-adjusted post-hoc tests (α = 0.05).

Results: Significant main effects were found for ΔE_{00} type ($F = 51.26$, $p < 0.001$, $\eta^2p = 0.647$) and group ($F = 18.9$, $p < 0.001$, $\eta^2p = 0.730$), with significant interaction ($F = 6.88$, $p < 0.001$, $\eta^2p = 0.496$). All daylight-exposed groups showed greater staining-related colour change than controls ($p < 0.05$), with no differences among exposure times. After polishing, 2- and 4-minute groups retained higher ΔE_{00} values than controls, whereas 6-minute group showed lower polishing-related change than 2- and 4-minute groups. For total colour change, 6-minute group demonstrated highest residual ΔE_{00} values ($p < 0.05$). Both controls remained below clinical perceptibility threshold ($\Delta E_{00} = 1.8$).

Conclusions: Daylight exposure before polymerisation did not increase susceptibility to coffee staining. Although polishing reduced discolouration, colour changes in experimental groups remained clinically unacceptable.

Keywords: Colour change, CIEDE2000, composite resin, polishing

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ÖZ

Amaç: Bu çalışma, ışık engelleyici kapağın açık kaldığı karıştırma plağında malzemenin kalması senaryosunu simüle ederek, kompozit rezinin gün ışığına maruziyeti sonrası renk değişimini değerlendirdi. Kahve lekelenme sonrası polisaj ile renk geri kazanımının etkisi de incelendi.

Gereç ve Yöntemler: Otuz beş disk şeklinde nano-hibrit kompozit örnek (NeoSpectra ST, Dentsply Sirona) beş gruba rastgele dağıtıldı (n = 7): negatif kontrol (gün ışığına maruziyet yok, lekelenme yok), pozitif kontrol (0-dakika gün ışığına maruziyet, lekelenme var), ve polimerizasyon öncesi 2, 4 veya 6 dakika doğal gün ışığına maruz kalan üç deney grubu. Kürleme sonrası, örneklerin bir yüzeyi üretici talimatlarına göre Sof-Lex disklerle (3M ESPE) kaba'dan ince'ye polisajlandı. Spektrofotometre (VITA Easyshade V) ile başlangıç renk ölçümleri (T_0) alındı. Negatif kontrol hariç, örnekler 7 gün kahvede bekletildi ve yeniden ölçüldü (T_1). Yeniden polisaj sonrası final ölçümleri (T_2) kaydedildi. Lekelenme (T_0–T_1), polisaj (T_1–T_2) ve toplam değişim (T_0–T_2) için CIEDE2000 formülü ile renk farkları (ΔE_{00}) hesaplandı. Veriler tekrarlı ölçümler ANOVA ve Bonferroni düzeltmeli post-hoc testlerle analiz edildi (α = 0.05).

Bulgular: ΔE_{00} tipi ($F = 51.26$, $p < 0.001$, $\eta^2p = 0.647$) ve grup ($F = 18.9$, $p < 0.001$, $\eta^2p = 0.730$) için anlamlı ana etkiler bulundu ($F = 6.88$, $p < 0.001$, $\eta^2p = 0.496$). Tüm gün ışığı grupları kontrollere göre daha fazla lekelenme kaynaklı renk değişimi gösterdi ($p < 0.05$), maruziyet süreleri arasında fark yoktu. Polisaj sonrası, 2- ve 4-dakika grupları kontrollere göre yüksek ΔE_{00} değerleri korudu, 6-dakika grubu ise diğer gruplara göre daha düşük polisaj kaynaklı değişim gösterdi. Toplam renk değişiminde, 6-dakika grubu en yüksek rezidüel ΔE_{00} değerlerini gösterdi ($p < 0.05$). Her iki kontrol klinik algılanabilirlik eşiğinin ($\Delta E_{00} = 1.8$) altında kaldı.

Sonuçlar: Polimerizasyon öncesi gün ışığı maruziyeti kahve lekelenme duyarlılığını artırmadı. Polisaj renk bozulmayı azaltmasına rağmen, deney gruplarındaki renk değişiklikleri klinik olarak kabul edilemez düzeyde kaldı.

Anahtar Kelimeler: Renk değişimi, CIEDE2000, kompozit rezin, cilalama

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Introduction

Recently, there has been a significant rise in the clinical application of resin composites for direct restorations in anterior and posterior teeth. Several variables are responsible for this growth, including the simplicity of bonding processes, advancements in resin composite compositions, and rising patient expectations for aesthetic outcomes.[1,2] Notwithstanding these advances, colour stability remains a salient issue that impacts the long-term aesthetic success of resin composites.[3,4]

Since their introduction, resin-based materials have been reported to undergo discolouration upon exposure to staining agents such as coffee, tea, red wine, and other pigmented beverages commonly consumed in daily life.[5,6] Although recent innovations in filler technology and resin matrices have improved the physical and mechanical properties of these materials[7], susceptibility to staining continues to be a clinical concern.

Resin composites are prone to both intrinsic and extrinsic discolouration. Intrinsic factors include chemical changes within the resin matrix, oxidation of unreacted double bonds, and degradation of photoinitiators and pigments over time.[8] Extrinsic discolouration, on the other hand, is mainly associated with incomplete polymerization, surface roughness, water sorption, and the adsorption of pigments from dietary sources or smoking, as well as inadequate oral hygiene.[9,10] These factors collectively contribute to gradual colour alteration, which may compromise the esthetic quality and clinical longevity of restorations.

Nano-hybrid resin composites are composed of a combination of nano-sized and conventional filler particles, enabling higher filler loading and a more homogeneous filler–resin matrix interface, which positively affects surface smoothness and optical properties.[11] This optimized filler structure has been shown to improve polishability and long-term polish retention, resulting in reduced surface roughness and lower susceptibility to extrinsic discoloration.[12,13] In addition, the decreased resin matrix exposure in nano-hybrid composites limits water sorption and pigment penetration, which are critical factors influencing color stability.[14]

NeoSpectra ST (Dentsply Sirona, Germany) is a nano-hybrid resin composite incorporating SphereTEC™ filler technology, characterized by pre-polymerized spherical filler granules combined with nano-sized particles, allowing improved filler–matrix integration and favorable surface characteristics[11]. Previous studies have reported that nano-hybrid composites demonstrate enhanced polish retention and resistance to discoloration after exposure to common staining agents, supporting their use in restorations where long-term esthetic stability is required.[15,16]

A review of the existing literature reveals that, although numerous studies have investigated the discolouration of resin composites under various conditions, no research has specifically evaluated the effect of daylight exposure prior to polymerization on the colour stability of these materials. This study was therefore designed to investigate the influence of daylight exposure on the colour change of a resin composite, simulating a clinical situation in which the light-blocking plate of the composite mixing plate is inadvertently left open during application. Furthermore, the study aimed to assess the extent to which the discolouration could be mitigated by a repolishing procedure performed after staining

The following were the null hypotheses examined in this study:

- H_{01}: Exposure to daylight before polymerization for different periods of time does not affect the colouration of the composites.
- H_{02}: Storage in coffee solution does not affect the colouration of the composite samples.
- H_{03}: The repolishing protocol does not make any difference in the composite colour change.

Materials and Methods

Specimen Preparation

A power analysis was conducted using G*Power 3.1.9.6 software based on pilot study results. Six specimens per group were considered sufficient to achieve a statistical power of 0.80 at an α level of 0.05.

A total of 35 disc-shaped composite resin specimens were fabricated using a nano-hybrid composite material (NeoSpectra ST, Dentsply Sirona, Germany). A cylindrical Teflon mold (5 mm diameter, 2 mm thickness) was used to prepare the specimens. To obtain a smooth surface, the composite resin was placed into the mold in a single increment, covered with a Mylar strip and a glass slide, and light-cured for 20 s at 1200 mW/cm² using an LED curing unit (Valo, Ultradent Products, UT, USA). The light intensity was verified using a radiometer prior to each use to ensure consistent polymerization conditions.

In this study, a clinical scenario was simulated in which the light-blocking plate of the composite resin container was inadvertently left open, allowing unintentional exposure to natural daylight prior to clinical use. Daylight exposure was performed under natural daylight conditions between 12:00 and 14:00 to ensure maximal and consistent illumination. Accordingly, the specimens were randomly divided into five groups (n = 7 per group): one negative control group (no daylight exposure, no staining) and four experimental groups exposed to natural daylight for 0, 2, 4, or 6 minutes prior to polymerization. The 0-minute group served as a positive control, receiving no daylight exposure but undergoing the same staining protocol as the experimental groups.

Negative Control: Specimens were prepared immediately and protected from any light exposure using a light-blocking plate. This group was not subjected to coffee staining.

0-minute daylight exposure group (Positive Control): Specimens were not exposed to daylight prior to polymerization but were subjected to the staining protocol.

2-minute daylight exposure group: Specimens were exposed to natural daylight for 2 minutes prior to polymerization.

4-minute daylight exposure group: Specimens were exposed to natural daylight for 4 minutes prior to polymerization.

6-minute daylight exposure group: Specimens were exposed to natural daylight for 6 minutes prior to polymerization.

After polymerization, all specimens were removed from the molds. One surface of each specimen was marked using a round bur, while the opposite surface was finished using the Sof-Lex polishing disc system (3M ESPE, USA) according to the manufacturer's instructions to eliminate surface irregularities. All polishing procedures were carried out by the same operator under standardized gentle manual pressure and constant rotational speed to minimize procedural variability among specimens.

Color Measurement

Color measurements were performed using a clinical spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, Bad Säckingen, Germany). Each specimen was positioned on a standardized background, and measurements were obtained from the central region of the upper surface using the single tooth mode. All measurements were conducted according to the CIE Lab* color system. The device was calibrated before each session following the manufacturer's recommendations. For each specimen, three consecutive measurements were recorded and averaged.

Baseline color measurements (T_0) were obtained after immersion of the specimens in distilled water at 37°C for 24 h. Subsequently, all groups except the negative control were immersed in a freshly prepared coffee solution (Nescafé Classic, Nestlé, Switzerland; 3.6 g coffee powder per 300 mL distilled water) for 7 days to induce staining.[17] The solution was renewed daily. After the staining period, color measurements were repeated (T_1).

After rinsing with distilled water and gentle drying with blotting paper, color differences were calculated as ΔE_{00} values. [18]

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'_{ab}}{K_S S_C}\right)^2 + \left(\frac{\Delta H'_{ab}}{K_H S_H}\right)^2 + R_T \left(\frac{\Delta C'_{ab}}{K_S S_C}\right)\left(\frac{\Delta H'_{ab}}{K_H S_H}\right)}$$

In the CIEDE2000 formula, ΔL*, ΔC*, and ΔH* represent differences in lightness, chroma, and hue, respectively, while R_T denotes the interaction term between chroma and hue differences. The parametric factors K_L, K_C, and K_H were set to 1, as recommended for laboratory studies. A ΔE_{00} value ≥ 1.8 was considered the 50% perceptibility threshold, corresponding to the clinically acceptable limit of color difference in dental materials.

Following staining, all specimens were repolished using the Sof-Lex polishing disc system (medium, fine, and superfine grits) according to the manufacturer's instructions. Each polishing step was applied for 20 s under light pressure at a constant speed using a low-speed handpiece. After polishing, the specimens were rinsed, air-dried, and subjected to a final color measurement (T_2).

Statistical Analysis

Statistical analyses were performed using jamovi software (version 2.6.44.0). Color changes were expressed as ΔE_{00} values calculated for staining (T_0–T_1), polishing-related color change (T_1–T_2), and total color change (T_0–T_2). A repeated-measures ANOVA was conducted with ΔE_{00} type as the within-subject factor and group as the between-subject factor. The ΔE_{00} type × group interaction was evaluated to assess differences in time-dependent color changes among groups. Sphericity was assessed using Mauchly's test, and when violated, the Greenhouse–Geisser correction was applied. Homogeneity of variances was evaluated using Levene's test. Post-hoc pairwise comparisons were performed with the Bonferroni adjustment. Effect sizes were reported as partial eta squared ($\eta^2 p$). Statistical significance was set at $p < 0.05$.

Results

The repeated-measures ANOVA revealed a significant main effect of ΔE_{00} type ($F = 51.26$, $p < 0.001$, $\eta^2 p = 0.647$), indicating that color changes differed significantly among staining (T_0–T_1), polishing-related change (T_1–T_2), and total color change (T_0–T_2). A significant ΔE_{00} type × group interaction was also observed ($F = 6.88$, $p < 0.001$, $\eta^2 p = 0.496$), demonstrating that the pattern of color change across these phases differed among the experimental groups. In addition, a significant main effect of group was detected ($F = 18.9$, $p < 0.001$, $\eta^2 p = 0.730$).

Mauchly's test indicated a violation of sphericity for the within-subject factor ($p < 0.001$); therefore, the Greenhouse–Geisser correction was applied. Levene's test confirmed homogeneity of variances for all ΔE_{00} variables ($p > 0.05$).

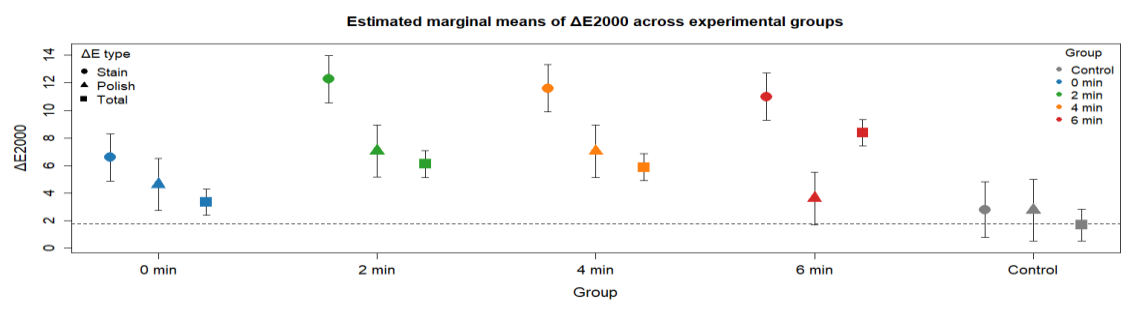


Figure 1. Estimated marginal means (± 95% confidence intervals) of ΔE2000 values for staining (T0–T1), polishing-related color change (T2–T1), and total color change (T2–T0) across the experimental groups. Colors represent the daylight exposure groups, while different symbols indicate the ΔE type. The dashed horizontal line denotes the clinical acceptability threshold (ΔE2000 = 1.8).

Post-hoc Analyses

Bonferroni-adjusted post-hoc comparisons were conducted to explore the significant interaction effect.

For ΔE_{00} (T_0–T_1), all daylight-exposed groups (2, 4, and 6 min) exhibited significantly greater staining-related color change than both the negative and positive control groups ($p < 0.05$), while no significant differences were observed among the daylight exposure durations.

For ΔE_{00} (T_1–T_2), polishing reduced color differences in all stained groups. However, specimens exposed to 2 and 4 min of daylight retained significantly higher polishing-related ΔE_{00} values compared with the control groups ($p < 0.05$). In contrast, the 6-min daylight exposure group showed significantly lower polishing-related color change than the 2- and 4-min groups ($p < 0.05$).

For ΔE_{00} (T_0–T_2), representing the overall residual color change, the 6-min daylight exposure group exhibited the highest ΔE_{00} values and differed significantly from all other groups ($p < 0.05$). Both control groups demonstrated the lowest overall color changes.

The interaction pattern is illustrated in Figure 1, which presents the estimated marginal means and 95% confidence intervals of ΔE_{00} values across groups and ΔE_{00} types.

Discussion

In the present study, we investigated the effect of inadvertent daylight exposure prior to polymerization on the colour stability of a nano-hybrid resin composite and evaluated the influence of repolishing on the removability of coffee-induced discolourations. The colour changes were assessed using the CIEDE2000 (ΔE_{00}) formula across three clinically relevant phases: staining (T_0–T_1), polishing-related colour change (T_1–T_2), and overall residual colour change (T_0–T_2). Based on these outcomes, all three null hypotheses were rejected, since daylight exposure duration, coffee staining, and repolishing procedures significantly influenced color change values.

In our study, immersion in coffee produced a statistically and clinically significant increase in ΔE_{00} values compared with the negative control, confirming the strong staining potential of coffee on resin-based composites. This finding is consistent with multiple recent investigations identifying coffee as one of the most potent extrinsic staining agents due to its high concentration of chromogenic compounds such as polyphenols and tannins, which can both adsorb onto the composite surface and penetrate the resin matrix.[19,20] Mechanistically, these low-molecular-weight chromophores may diffuse into hydrophilic domains of the polymer network, particularly following water sorption, resulting in both superficial and subsurface discoloration. Accordingly, recent studies continue to report coffee consumption as a primary contributor to clinically relevant ΔE_{00} increases in contemporary resin composites.[19,21]

Repolishing after staining significantly reduced ΔE_{00} values across all stained groups, indicating that removal of the superficially stained resin layer and surface smoothing can improve colour outcomes. This observation is in agreement with previous in vitro studies demonstrating that repolishing procedures and polishing system selection substantially influence stain removal efficiency. Bulut et al.[22] showed that although repolishing reduced discoloration in single-shade resin composites, residual ΔE_{00} values often remained clinically perceptible. Similarly, Uçtaşlı et al.[23] reported significant colour recovery after repolishing; however, coffee-stained specimens continued to exhibit the highest residual colour changes. In line with Aksoy Vaizoğlu et al.[24] the present findings indicate that while polishing improves esthetic appearance, it may not completely reverse staining when pigments penetrate deeper into the resin matrix. Importantly, in the current study, residual ΔE_{00} values following repolishing frequently remained above the clinical acceptability threshold ($\Delta E_{00} \geq 1.8$), particularly in daylight-exposed groups, emphasizing the clinical relevance of surface maintenance but also its limitations.[22,25]

The daylight exposure durations applied in this study were designed to simulate inadvertent clinical handling errors rather than optimal restorative protocols. In routine practice—especially in teaching or high-volume clinical settings—composite syringes or compules may remain unintentionally uncovered under ambient daylight during restorative procedures. The selected exposure times (0, 2, 4, and 6 minutes) were therefore chosen to represent progressively prolonged accidental exposure scenarios, corresponding to the approximate duration required for composite placement and contouring in direct restorations. Notably, preliminary observations indicated that exposure beyond 6 minutes resulted in visible premature polymerization under daylight conditions, supporting the clinical plausibility of the selected intervals.

Short-term daylight exposure prior to polymerization did not significantly increase staining susceptibility during the staining phase (T_0–T_1), suggesting that brief ambient light exposure may not induce sufficient alterations in polymer network formation or surface characteristics to enhance chromogen uptake. This finding is consistent with previous reports indicating that modest variations in light exposure or polymerization conditions do not necessarily translate into clinically meaningful differences in colour stability for modern resin composites.[26,27] However, when overall color change (T_0–T_2) was evaluated, the 6-min daylight exposure group exhibited the highest residual ΔE_{00} values after repolishing despite showing lower polishing-related color change than the 2- and 4-min groups. This finding suggests that prolonged daylight exposure prior to polymerization may have altered the polymerization kinetics and promoted a more stable intrinsic discoloration that could not be completely removed by surface polishing. The persistence of residual discoloration after repolishing further indicates that extended pre-polymerization daylight exposure adversely affected the optical stability of the resin matrix.

The nano-hybrid structure of the composite used in this study may have contributed to the relatively lower color changes observed in the control groups. Nano-hybrid composites possess smaller and more uniformly distributed filler particles, which improve surface smoothness and reduce plaque and pigment accumulation. Previous investigations demonstrated that smoother composite surfaces exhibit reduced extrinsic staining because fewer surface irregularities are available for pigment retention.[9,28] Nevertheless, despite the favorable filler characteristics of the tested material, daylight exposure prior to polymerization significantly increased discoloration susceptibility.

The interpretation of these results should be made in light of certain limitations. This was an in vitro study conducted under controlled laboratory conditions that do not fully replicate the complex oral environment, including thermal fluctuations, salivary enzymes, mechanical abrasion, and dietary variability. In addition, only one nano-hybrid composite material and shade were evaluated, and different resin formulations, filler systems, or photoinitiator chemistries may respond differently to daylight exposure. Furthermore, staining was limited to coffee immersion; other chromogenic agents such as tea, red wine, or cola may produce different discoloration patterns. Finally, colour measurements were performed on flat disc specimens, which do not replicate the anatomical contours or surface textures of clinical restorations. Future studies incorporating multiple composite systems, extended exposure scenarios, and long-term aging protocols are warranted to further elucidate the clinical implications of inadvertent daylight exposure on composite colour stability.

Conclusions

Within the limitations of this current in vitro study, it was concluded that:

- Daylight exposure before polymerization significantly increased the discoloration susceptibility of the nano-hybrid resin composite after coffee staining.
- Coffee immersion significantly affected the color stability of all stained groups, resulting in increased ΔE_{00} values compared with the negative control group.
- Repolishing significantly reduced color change values in stained specimens; however, residual discoloration remained higher in daylight-exposed groups, particularly after prolonged exposure periods.

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Conflicts of Interest Statement

The author declare that they have no conflict of interest.

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