DOI: https://doi.org/10.54617/adoklinikbilimler.1555752

Original Research Article

Effect of Energy Drinks on Color Stability and Surface Roughness of Nanohybrid and Micro-Hybrid Resin Composites

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ABSTRACT

Aim: This study was to evaluate the color stability and surface roughness of conventional resin composites after immersion with two different energy drinks.

Materials and Methods: 66 disc specimens (6 x 2 mm) were prepared from micro-hybrid (G-ænial Posterior) and nano-hybrid (Clearfil Majesty Esthetic) resin composites. Post-polymerization was conducted by storing all specimens in distilled water at 37 °C for 24 hours. Baseline color and surface roughness (Ra) measurements were performed, after which the specimens were randomly divided into three groups (n=11/subgroup) according to the immersion solution used: Group 1 (distilled water), Group 2 (Red Bull), and Group 3 (Burn). After 7 days of immersion, final measurements were recorded. Color variations (ΔE_{00}) were determined using a spectrophotometer and the CIEDE2000 formula before and after the immersion. Data were subjected to ANOVA analysis ($\alpha = 0.05$).

Results: There were no statistically significant differences in color stability between the nanohybrid and micro-hybrid resin composites ($p > 0.05$). Both resin composites exhibited color changes exceeding the AT threshold (> 1.8) and the PT threshold (> 0.8). The highest ΔE_{00} values were found in the specimens exposed to Red Bull. Specimens in distilled water showed ΔE_{00} values below the AT threshold (< 1.8). In terms of Ra values, significant differences were noted between the materials in both the Ra0 and Ra1 measurement intervals ($p < 0.001$ and $p = 0.002$). The Clearfil Majesty Esthetic specimens had the highest surface roughness, with Red Bull resulting in the greatest Ra values.

Conclusion: Over the 1-week immersion period, all tested solutions led to increased color changes and surface roughness in the restorative materials.

Keywords: Color stability; Energy drink; Resin composite; Surface roughness

Citation: Atılan Yavuz S, Ertürk Avunduk AT, Yıdız G, Cengiz Yanardağ E. Effect of Energy Drinks on Color Stability and Surface Roughness of Nanohybrid and Micro-Hybrid Resin Composites. ADO Klinik Bilimler Dergisi 2026;15(2):86-94

Editor: Sinem Akgül, Gazi University, Ankara, Türkiye.

INTRODUCTION

Resin composites serve as esthetic restorative materials for both anterior and posterior applications. The size and quantity of fillers significantly influence the physical and mechanical properties of these composites. Despite ongoing advancements by manufacturers to enhance these properties, resin composites remain vulnerable to chemical degradation.[1] This degradation can adversely affect surface roughness, leading to increased susceptibility to staining.[2]

The quality of the surface of resin composite restorations is critical for their long-term clinical success. Increased surface roughness can promote plaque accumulation, resulting in undesirable stained restorations and potential failure.[3] Factors effecting the clinical performance of resin composites include filler content, particle size, instruments used, finishing techniques, and environmental influences in the oral cavity. Notably, composites with smaller filler sizes tend to exhibit smoother surfaces. Nanotechnology-based composites, which incorporate nanofillers, are designed to enhance clinical outcomes compared to their microhybrid counterparts, thanks to the inclusion of sub-micrometer particles that improve optical and physical properties.[4]

Received: 09.27.2024; Accepted: 02.03.2026
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Recently, energy drink consumption has surged, particularly among adults aged 18 to 35, who often seek these beverages for energy and fatigue relief. Energy drinks typically contain caffeine, taurine, glucuronolactone, vitamin B, and citric acid, the latter contributing to their low pH.[5] This acidic environment can compromise restorative dental materials by leaching fillers from the resin matrix, resulting in increased surface roughness. Furthermore, the synthetic dyes in these drinks can negatively impact the color stability of various resin restorative materials through both adsorption and absorption processes.[6]

Based on our knowledge, little information is available about the effect of energy drinks on the color stability and structural effects of resin composites. Given the routine consumption of acidic beverages like energy drinks, this study aimed to evaluate the impact of various energy drinks on the color change and surface roughness of micro-hybrid and nano-hybrid resin composites. The null hypotheses tested in this study were: i) There is no difference in color change among resin composites when exposed to different energy drinks; ii) There is no difference in surface roughness among resin composites due to different energy drinks.

MATERIALS AND METHODS

This study adhered to the ethical principles outlined in the Declaration of Helsinki and received approval from the Clinical Research Ethics Committee of Mersin University (no. 2024/885).

The study examined two independent variables: types of resin composites and various energy drinks. The dependent variables were color change and surface roughness. Sample size calculations were performed using G*Power software (Version 3.1.9.4, Heinrich Heine University, Düsseldorf, Germany), with a significance level of 0.05 and a power of 80%, resulting in the required sample size of 66 specimens. A flowchart of the study design is presented in Figure 1.

1. Specimen preparations

A total of 66 standardized disc specimens (6 x 2 mm) were prepared using a Teflon mold, creating 33 specimens for each restorative material: microhybrid resin composite (G-ænial Posterior (GP), GC Dental Products, Alsip, IL, USA) and nanohybrid resin com-

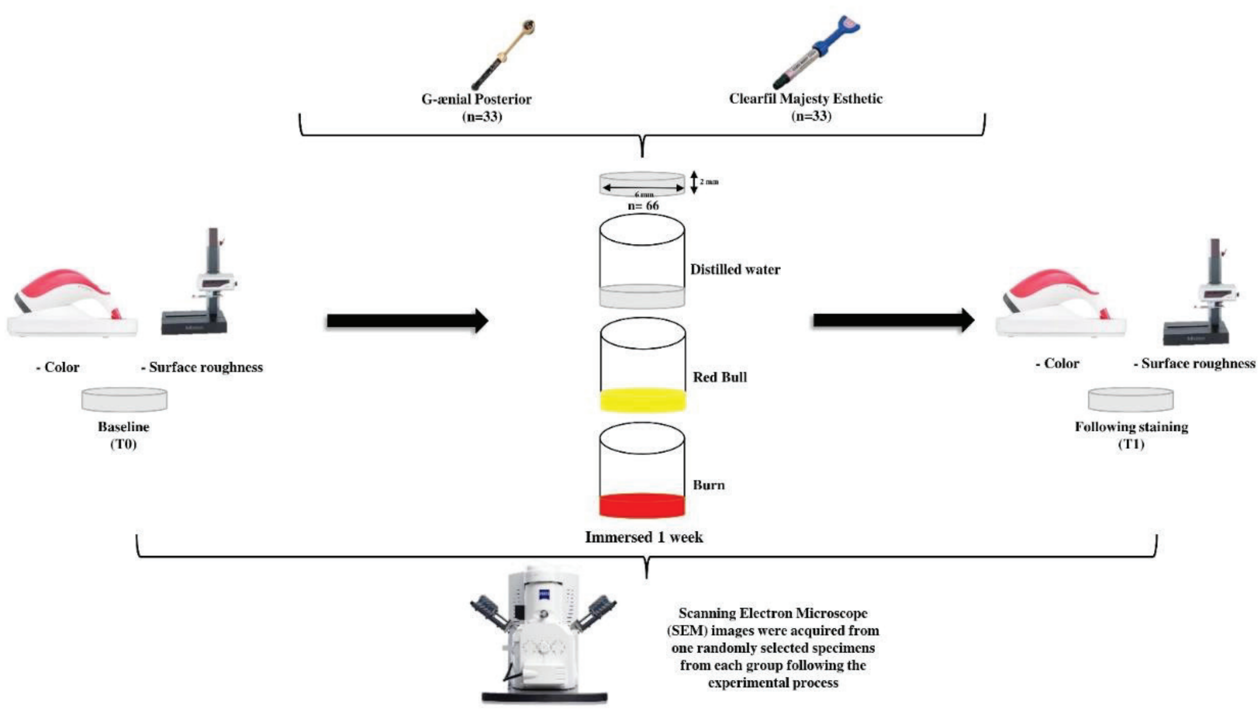

Figure 1. Flow chart of the study.

posite (Clearfil Majesty Esthetic (CME), Kuraray, Okayama, Japan). A glass plate and a Mylar strip were employed to ensure uniform thickness and consistent distance from the light-curing tip during polymerization. Specimens were polymerized with a light emitting diode (LED) light-curing unit (SmartLite Pro, Dentsply, Germany) at a light intensity of 1200 mW/cm² for 20 seconds. After polymerization, specimens were polished with aluminum oxide-impregnated discs (SofLex, 3M ESPE, St. Paul, MN, USA), immersed in distilled water for post-polymerization, and stored at 37 °C for 24 hours. Specimens were then divided into three groups (n = 11) based on immersion solutions: Group 1 (distilled water), Group 2 (Red Bull GmbH, pH ≈ 3.54), and Group 3 (Burn, The Coca-Cola Co., pH ≈ 2.67). Details regarding the manufacturers and compositions of the restorative materials and energy drinks are provided in Table 1.

2. Immersion solutions preparation

A pH meter (Hanna Instruments, Padova, Italy) was used to measure the pH levels of energy drinks. Specimens were immersed in containers ensuring full exposure to the staining solution. To minimize evaporation, solutions were sealed throughout the study. Specimens were maintained in an incubator at 37 °C, except during solution changes and measurements.

3. Color assessment process

Colorimetric evaluations were conducted at baseline (T0) and after immersion in energy drinks (T1) using a digital spectrophotometer (Vita Easyshade V; Vita Zahnfabrik, Bad Säckingen, Germany). Measurements were taken in triplicate, and mean values were recorded according to Commission Internationale de l'Eclairage (CIE) parameters. The spectrophotometer was calibrated before each test group measurement. Color differences (ΔE_{00}) were calculated using the CIEDE2000 formula:[7]

$$\Delta E_{00} = \left[\left(\frac{\Delta L}{k_L S_L}\right)^2 + \left(\frac{\Delta C}{k_C S_C}\right)^2 + \left(\frac{\Delta H}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C}{k_C S_C}\right)\left(\frac{\Delta H}{k_H S_H}\right)\right]^{1/2}$$

The parameters kL, kC, and kH serve as correction terms for experimental variations and were standardized to 1.0 in this study. CIEDE2000 values were assessed based on (PT) and (AT) thresholds of 0.8 and 1.8, respectively.[8]

Table 1. Composition and manufacturer information of restorative materials and energy drinks used in the study.

Product	Manufacturer	Composition	Code
G-ænial Posterior (A2) (Micro-hybrid composite resin)	GC, Dental Products, Alsip, IL, USA	UDMA, methacrylate monomers, ytterbium trifluoride, prepolymerized fillers, fluoroaluminosilicate, silica, camphorquinone and amine	GP
Clearfil Majesty Esthetic (A2) (Nano-hybrid composite resin)	Kuraray Noritake Dental, Tokyo, Japan	Bis-GMA, silanated barium glass filler, silanated silica filler, camphroquinone and pre-polymerized organic filler	CME
Red Bull	Red Bull GmbH, Austria	Water, sucrose, glucose, acidifier sodium citrates, carbon dioxide, taurine (0.4%), glucuronolactone (0.24%), caffeine (0.03%), inositol, vitamins (niacin, pantothenic acid, B6, B12), flavourings, and colours (caramel, riboflavin).	-
Burn	The Coca-Cola Company, Atlanta, Georgia	Carbonated water, sucrose, citric acid, taurine (0.4%), acidity regulator: sodium citrate, coloring agents: E163, E150d, preservatives: potassium sorbate, sodium benzoate, flavor, caffeine (0.03%), inositol, vitamins [nicotinamide (B3), d-calcium pantothenate, pyridoxine hydrochloride (B6), cyanocobalamin (B12)], seed extract of guarana (0.005%), antioxidants (ascorbic acid)	-

Abbreviations: Bis-GMA: bisphenol A glycerolate dimethacrylate; UDMA: urethane dimethacrylate.

4. Surface roughness assessment process

Surface roughness (Ra) was evaluated using a contact mode profilometer (Mitutoyo, Surftest SJ-410, Japan). The measuring distance was 4 mm and a cut-off value of 0.8 mm. Measurements were taken at three different locations for each specimen at baseline (T0) and following immersion (T1), with mean Ra values calculated. A Ra threshold of 0.2 μm was established.[9]

5. Experimental groups

After baseline measurements, specimens were randomly divided into three subgroups (n=11):

- Group 1: Control (Distilled water, no staining)
- Group 2: Immersed in Red Bull energy drink at 37°C for seven days
- •Group 3: Immersed in Burn energy drink at 37°C for seven days

The color and surface roughness measurements were repeated after staining (T1) process.

6. Scanning Electron Microscope (SEM) analysis

Two additional specimens from each material (GP and CME) were prepared for SEM analysis to represent Group 1 (control), Group 2 (Red Bull), and Group 3 (Burn). Specimens were sputter-coated with palladium and examined using a SEM (EVO 18; Zeiss, Wetzlar, Germany) at Mersin University Advanced Technology Education Research and Application Center, under specific magnification (x 5000) and voltage settings.

7. Statistical analysis

Data were analysed with the Statistical Package for the Social Sciences (SPSS Inc., Version 23, Chicago, IL, USA). The data's conformity to a normal distribution was evaluated using the Kolmogorov-Smirnov and Shapiro-Wilk tests. The mean values and standard deviations (SD) were compared using two-way ANOVA and Tukey's post hoc test at $p < 0.05$.

RESULTS

Table 2 displays the mean ΔE_{00} values of the restorative materials following immersion in various energy drinks. As the statistical analysis that there was no significant difference between the mean ΔE_{00} values according to the materials ($p > 0.05$). There was a statistically significant difference between the mean ΔE_{00} values according to the solutions ($p = 0.001$). The ΔE_{00} values of the staining groups (Red Bull and Burn) were obtained as 4.11 and 3.54. The control group was significantly different from the others. The mean ΔE_{00} value of the GP was 3.49 and 2.75 of the CME. The highest ΔE_{00} values was obtained with 6.34 of the GP*Red Bull interaction, while the lowest value was obtained with 0.71 of the GP*control group. In general, the color change of all interactions (except GP*control group) was exceeded the AT threshold (> 1.8) and PT threshold (> 0.8).

The mean Ra values and SD of the restorative materials are shown in Table 3. A statistically significant difference was observed between Ra0 and Ra1 values according to the material ($p < 0.001$ and $p = 0.002$). The total Ra0 and Ra1 values of the GP

Table 2. Descriptive statistics and multiple comparison results of ΔE_{00} according to restorative materials and solutions.

	ΔE_{00}		
	Restorative Materials		
Solutions	**GP**	**CME**	**Total**
Distilled water	0.71±0.29$^{A, a}$	2.56±1.38$^{B, b}$	1.64±1.36^{a}
Red Bull	6.34±4.50$^{B, b}$	2.03±1.18$^{A, a}$	4.11±3.89^{b}
Burn	3.41±1.80^{b}	3.66±1.28^{b}	3.54±1.52^{b}
Total	3.49±3.58	2.75±1.42	

Abbreviations: GP: G-ænial Posterior; CME: Clearfil Majesty Esthetic
A, b: Values indicated by different small letters on the same column are statistically significantly different
A, B: Values indicated by different big letters on the same line are statistically significantly different
* Two-way ANOVA, Tukey's post hoc test

Table 3. Descriptive statistics and multiple comparison results of Ra according to restorative materials and solutions.

		Ra		
		Restorative Materials		
Solutions		**GP**	**CME**	**Total**
Distilled water	Ra0	0.14 ± 0.09^{A}	0.66 ± 0.66^{B}	0.40 ± 0.53
	Ra1	0.47 ± 0.52	0.62 ± 0.68	0.55 ± 0.59^{y}
Red Bull	Ra0	0.13 ± 0.12	0.29 ± 0.19^{a}	0.21 ± 0.18^{a}
	Ra1	0.36 ± 0.45^{A}	$1.40 \pm 1.04^{B, b}$	$0.88 \pm 0.89^{b, x}$
Burn	Ra0	0.18 ± 0.14^{A}	0.59 ± 0.34^{B}	0.39 ± 0.33
	Ra1	0.20 ± 0.19^{A}	0.97 ± 0.95^{B}	0.58 ± 0.77^{y}
Total	Ra0	$0.15 \pm 0.12^{A, a}$	$0.51 \pm 0.46^{B,a}$	
	Ra1	$0.34 \pm 0.41^{A, b}$	$0.92 \pm 0.90^{B,b}$	

Abbreviations: GP: G-ænial Posterior; CME: Clearfil Majesty Esthetic
a, b: Values indicated by different small letters on the same column are statistically significantly different
x, y: Values indicated by different small letters on the same column are statistically significantly different (for total Ra1 values of staining solutions)
A, B: Values indicated by different big letters on the same line are statistically significantly different
* Two-way ANOVA, Tukey's post hoc test

(0.15 and 0.34) were significantly higher than CME (0.51 and 0.92). There was a statistically significant difference between the mean Ra1 values according to the solutions (p = 0.002). The Ra1 values of the groups were 0.55, 0.88, and 0.58, respectively. Red Bull group was statistically different from the others. Regardless of the restorative material used, the Ra1 value of all energy drinks was significantly higher than the Ra0 value in Group 2, and similar in Group 1 and Group 3. While the highest Ra1 values was obtained with 1.40 in CME*Red Bull interaction, the lowest Ra0 values was in GP*Red Bull interaction.

Figure 2 presents SEM images of each restorative material (GP and CME). The SEM micrographs of the CME specimens treated with Red Bull exhibited increased surface porosity (Figure 2.e). Furthermore, the CME specimens showed more alterations compared to GP, particularly after immersion in Red Bull and Burn (Figure 2e-b and Figure 2f-c, respectively).

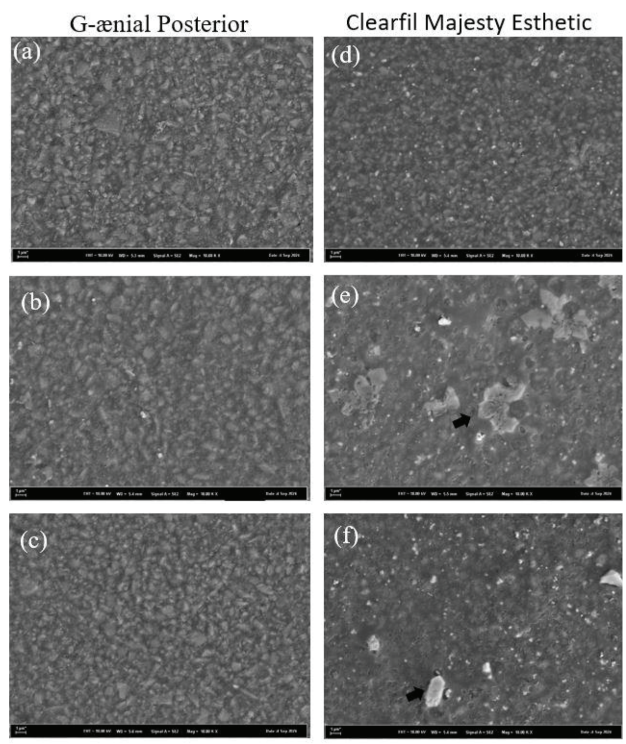

Figure 2. SEM images of the experimental groups a) Distilled water*G-ænial Posterior b) Red Bull*G-ænial Posterior c) Burn*G-ænial Posterior d) Distilled water*Clearfil Majesty Esthetic e) Red Bull*Clearfil Majesty Esthetic f) Burn*Clearfil Majesty Esthetic.

DISCUSSION

Dental resin composites can easily stain from food and beverages in the oral cavity, primarily due to the interaction between external colorants and the resin. Colorants can either adhere to the surface or penetrate the resin matrix, resulting in discoloration that negatively effects esthetics.[10] Moreover, exposure to acidic staining solutions may alter the mechanical, physical, and esthetic properties of these restorative materials.[11] This study aimed to investigate how various energy drinks effect the color stability and surface roughness of micro-hybrid and nano-hybrid resin composites. The first hypothesis was supported, as the restorative materials showed comparable color changes after immersion in energy drinks.

The results indicated that all resin composites tested exhibited significant color changes beyond clinically AT (> 1.8). Among the materials, the micro-hybrid composite (GP) was more susceptible to color change than the nano-hybrid composite (CME). This aligns with previous findings indicating that nano-hybrid composites generally show better resistance to staining.[12] The resin matrix's type and composition influence its hydrophilicity, which is crucial for long-term color stability. Factors like filler size and distribution also effect surface roughness, polishability, and water absorption.[13] While a higher filler-to-resin ratio could lower water absorption and staining susceptibility, the size of the fillers remains debated, especially when comparing micro-hybrid and nano-hybrid composites. In nano-hybrid composites, smaller particles may break off during polishing, creating fewer voids than in micro-hybrids.[14] Thus, it's expected that the nano-hybrid composite with smaller particle size would show less color change in this study.

The color stability of resin composites was evaluated by immersing them in two energy drinks (Red Bull and Burn) and distilled water as a control for one week. Previous reviews noted that immersion periods in studies varied greatly, from 1 to 365 days, with many using a 7-day duration, which typically led to notable color changes that exceeding the PT and AT.[15,16] Based on these findings, a 7-day immersion protocol was adopted for the specimens in the present study.

The study's findings demonstrated that both energy drinks produced substantial discoloration. This effect is attributed to the low pH values of the beverages, which soften the resin matrix and enhance pigment uptake.[5] Our study contradicts the findings of Erdemir *et al.*[8], as Red Bull exhibited a numerically higher, yet statistically nonsignificant, color change compared to Burn. These discrepancies are likely attributable to the extended immersion durations of 1 and 3 months applied in Erdemir *et al.*[17] experimental protocol.

In the present study, the highest ΔE_{00} value (6.34) was observed in the GP*Red Bull group. In contrast to our findings, a previous investigation evaluating the effects of various acidic fruit juices on microhybrid and nanohybrid resin composites reported greater color stability in the microhybrid material.[18] This inconsistency between the two studies is likely attributable to differences in the types of beverages and their respective pH levels.[18] Additionally, bisphenol A glycerolate dimethacrylate (Bis-GMA) based resin matrices are known to exhibit increased water sorption due to their hydrophilic characteristics, resulting in reduced stain resistance compared with other methacrylate monomers such as urethane dimethacrylate (UDMA).[19] In the present study, the statistically significant difference observed between the two restorative materials in distilled water is therefore attributed to the presence of Bis-GMA within the monomer composition of CME.

In the present study, the surface roughness of the micro-hybrid and nano-hybrid restorative materials were evaluated following exposure to acidic energy drinks, which are widely consumed. The two tested resin composites demonstrated significant changes in surface roughness after one week of immersion in the solutions. It is known that the surface roughness of the resin composites were effected to the filler type and size, type of resin matrix, and staining agent.[17] In the literature it has been reported that resin composites with smaller particle sizes exhibit lower surface roughness.[20] Although it was expected that a nanohybrid resin composite would show higher surface roughness than a microhybrid, in the current study, nano-hybrid CME had higher surface roughness than micro-hybrid GP. Sideridou *et al.*[21] reported that UDMA-based resins containing carbamate linkages exhibit less water sorption than Bis-GMA-based resins, containing highly polar hydroxyl groups. Contrary to expectations, it is thought that the higher surface roughness of CME is due to the Bis-GMA in its structure and the presence of UDMA in the structure of GP, which shows lower water absorption compared to Bis-GMA. And also, the previous studies were shown that glass filler particles tend to fall out from the material and the matrix component decomposes due to acidic environment.[22,23] Although CME has a nanohybrid structure, it has shown higher surface roughness, which can be attributed to the glass filler content.

Because many energy drinks exhibit pH values of 3.0 or lower, prolonged exposure has the potential to erode both tooth enamel and resin composite surfaces.[24] In accordance with previous literature, the results of the present study demonstrated that all energy drinks increased the surface roughness of the restorative materials; however, a statistically significant difference was observed only for Red Bull.[23,25] Consequently, the second null hypothesis—asserting that surface roughness would not differ among resin composites exposed to various energy drinks—was partially rejected. Although increased surface roughness was anticipated primarily in specimens exposed to the lower-pH beverage Burn (pH 2.67), Red Bull (pH 3.54) unexpectedly produced greater surface roughness in our study.

In dentistry, measurement devices such as contact profilometry, laser profilometry, SEM, and 3-dimensional (3D) optical profilometry are used for quantitative and qualitative measurement of surface roughness. However, after the contact profilometer, which provides quantitative findings, supporting it with qualitative data obtained from the SEM device increases the accuracy of surface roughness. As in many studies in the literature, the data obtained with the profilometer in the current study was supported and detailed by SEM images (Figure 2).[26,27] Considering the mean values obtained, it is seen that the highest surface roughness is in Figure 2.e in the SEM images, which supports the numerical data.

The resin composites tested in this in-vitro study do not represent all the experimental conditions to which restorative materials may be exposed in the complex oral environment. Therefore, the present study confirmed that acidic energy drinks had a detrimental effect on the color change and surface roughness of composite resin restorative materials, however it remained to be known if the durability of restorative materials would be thus adversely affected in the oral environment. Moreover, no mechanical assessment of the effect energy drinks on resin composites exists. Further studies are needed to investigate the long-term clinical and in-vitro performance of restorative materials against energy drinks.

CONCLUSION

Within the limitations of this study, it was concluded that all tested solutions increased the restorative materials' color change and surface roughness over a 1-week immersion period. Despite showing similar values, the nano-hybrid resin composite (CME) showed slightly lower color change than the micro-hybrid resin composite (GP). SEM analysis showed that before and after staining, regardless of solutions, micro-hybrid resin composite (GP) showed lower surface roughness than nano-hybrid resin composite (CME). Red Bull energy drink caused the greatest increase in both parameters of resin composites.

ACKNOWLEDGMENTS

The authors thank Seher Kuru, Mersin University Advanced Technology Education Research and Application Center, for SEM images.

CONFLICTS OF INTEREST STATEMENT

The authors declared that there is no conflict of interest.

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Enerji İçeceklerinin Nanohibrit ve Mikro-Hibrit Rezin Kompozitlerin Renk Değişimi ve Yüzey Pürüzlülüğü Üzerindeki Etkileri

ÖZET

Amaç: Bu çalışmanın amacı enerji içeceklerinin nano-hibrit ve mikro-hibrit rezin kompozitlerin renk değişimi ve yüzey pürüzlülüğü üzerindeki etkilerini değerlendirmektir.

Gereç ve Yöntemler: Her bir rezin kompozit [G-ænial Posterior (mikro-hibrit) ve Clearfil Majesty Esthetic (nano-hibrit)] için 33 örnek (6 x 2 mm) hazırlandı. Post-polimerizasyon için tüm numuneler, 24 sa 37 °C'de distile suda bekletildi. Renk ve yüzey pürüzlülüğünün (Ra) başlangıç ölçümlerinin ardından, numuneler test edilen solüsyonlara göre rastgele üç gruba (n = 11/grup) Grup 1 (distile su), Grup 2 (Red Bull) ve Grup 3 (Burn) dağıtıldı. Numuneler 1 hf boyunca enerji içeceği çözeltilerine daldırıldı. ΔE_{00} değerleri test prosedüründen önce ve sonra CIEDE2000 formülü kullanılarak bir spektrofotometre ile hesaplandı. Yüzey pürüzlülüğü ölçümleri tekrarlandı. İki yönlü varyans analizi ve Tukey'in post-hoc testi yapıldı. Anlamlılık düzeyi $p < 0.05$ olarak kabul edildi.

Bulgular: Nanohibrit ve mikro-hibrit rezin kompozitler arasında istatistiksel bir fark tespit edilmedi ($p > 0.05$). İki rezin kompozitin renk değişimi AT (> 1.8) ve PT eşiğinin (> 0.8) üzerindeydi. En yüksek ΔE_{00}, Red Bull ile muamele edilen numunelerde gözlendi. Distile suda ΔE_{00} değerleri AT eşiğinin altında kalmıştır (< 1.8). Ra değerlerine göre, hem Ra0 hem de Ra1 zaman periyotlarında restoratif materyaller arasında anlamlı farklılıklar görüldü (p = 0.000 ve p = 0.002). En yüksek yüzey pürüzlülüğü Clearfil Majesty Esthetic numunelerinde gözlendi. Red Bull enerji içeceği en yüksek Ra değerlerine neden oldu.

Sonuç: Test edilen tüm solüsyonlar, 1 hf daldırma süresi boyunca restoratif materyallerin renk değişimini ve yüzey pürüzlülüğünü artırmıştır.

Anahtar Kelimeler: Renk stabilitesi; Enerji içeceği; Rezin kompozit; Yüzey pürüzlülüğü