ORİJİNAL MAKALE / ORIGINAL ARTICLE

Düzce Üniversitesi Sağlık Bilimleri Enstitüsü Dergisi / DÜ Sağlık Bil Enst Derg
Journal of Duzce University Health Sciences Institute / J DU Health Sci Inst
ISSN: 2146-443X sbedergi@duzce.edu.tr 2021; 11(3): 284-289
doi: https://dx.doi.org/10.33631/duzcesbed.840660

Evaluation of Stain Susceptibility of Different CAD/CAM Blocks After Immersion in Coffee

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ABSTRACT

Aim: Color stability is gaining more importance today due to majority of patients are seeking color matching restorations. However, there is still lack of information on staining and changes in translucency of recent CAD/CAM block materials. The goal of the current study was to evaluate the discoloration susceptibility, translucency change, water solubility, and water sorption of different CAD/CAM materials after one-month of immersion in coffee.

Material and Methods: Four CAD/CAM block materials and one conventional composite resin were examined. The CIELab values of CAD/CAM materials were determined using a clinical spectrophotometer on black and white backgrounds. The color changes and translucency differences were calculated after immersion in coffee or distilled water for one month (n=6). Water solubility and sorption were also determined according to the ISO 4049:2009 (n=6). The data were calculated by 2-way ANOVA and Tukey's pair-wise comparisons ($\alpha=0.05$).

Results: Color changes of the CAD/CAM materials tested ranged from 1.5 to 7.3, and translucency reduced. The highest color change was observed in nanocomposite resin (7.3), whereas the lowest color change was observed in feldspathic porcelain (1.5) after storing in coffee for a month. There was no significant difference among the polymer-based CAD/CAM materials. No correlation was determined between color changes and water sorption/solubility.

Conclusion: All materials except feldspar ceramic showed a discoloration exceeding the clinically acceptable threshold level (2.7) after being stored in coffee for one month. The highest color change was observed in nanocomposite resin material.

Keywords: CAD/CAM; color stability; resin composites; stainability; staining

Kahvede Bekletilen Farklı CAD/CAM Blokların Renk Stabilitelerinin Değerlendirilmesi

ÖZ

Amaç: Renk uyumu, hastaların estetik olarak uyumlu restorasyon arayışlarının artması nedeniyle günümüzde daha da önem kazanmıştır. Bununla birlikte, mevcut CAD/CAM blokların renk değişikliği ve translusentliklerindeki değişiklikler hakkında hala bilgi eksikliği bulunmaktadır. Bu çalışmanın amacı, kahvede bir ay bekletme süresinin ardından farklı CAD/CAM blokların renk stabilitesinin, translusentliğinin, su emiliminin ve suda çözünürlüğünün araştırılmasıdır.

Gereç ve Yöntemler: Dört CAD/CAM blok materyali ve bir geleneksel kompozit reçine değerlendirilmeye alınmıştır. Örnekler 2 mm kalınlığında hazırlanmıştır ve örneklerin CIELab değerleri, siyah ve beyaz arka plan üzerinde klinik spektrofotometre ile ölçülmüştür (n=6). Kahve veya distile suda bir ay bekletildikten sonra renk ve translusentlik değişimleri hesaplanmıştır. Su emilimi ve suda çözünürlük değerleri ayrıca ISO 4049: 2009'a göre belirlenmiştir (n=6). Veriler iki yönlü ANOVA ve Tukey'in ikili karşılaştırmalarıyla analiz edilmiştir ($\alpha=0,05$).

Bulgular: CAD/CAM blokların renk değişimleri 1,5 ile 7,3 arasında bulunmuş ve translusentlikleri azalmıştır. Bir aylık kahvede bekletilme sonucunda, en yüksek renk değişimi nano kompozit reçinede (7,3) gözlenirken en düşük renk değişimi feldspatik porselende (1,5) gözlenmiştir. Polimer bazlı CAD/CAM materyaller arasında istatistiksel olarak anlamlı bir fark bulunmamaktadır. Renk değişiklikleri ile su emilimi veya suda çözünürlük arasında korelasyon bulunmamıştır.

Sonuç: Feldspat seramik hariç tüm materyaller kahve içerisinde bir ay bekletildikten sonra klinik olarak kabul edilebilir eşik seviyesini (2.7) aşan bir renk değişikliği göstermiştir. En yüksek renk değişimi nano kompozit reçine materyalde gözlenmiştir.

Anahtar Kelimeler: CAD/CAM; renk stabilitesi; reçine kompozitler; renklenebilirlik; renklenme

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Geliş Tarihi / Received: 14.12.2020, Kabul Tarihi / Accepted: 16.05.2021

INTRODUCTION

Dentistry is an area where aesthetic expectations are increasing. Nowadays, the success of restorative materials is determined not only by its mechanical and physical properties, but also by its aesthetic appearance (1,2). Shade selection and color stability are important criteria in the success of the aesthetic treatments (3,4). In this context, tooth-colored restorative materials are expected to have the optimum color matching and color stability (5,6). Dental ceramics enable aesthetic restorations by mimicking the fluorescence and translucency of natural tooth (7). However, dental ceramics are rigid materials with low fracture toughness and high brittleness, which limit their clinical performance.

Color stability is a crucial factor for long-term aesthetic outcome (8, 9). Composite resins are more susceptible to aging related degradation pathways compared to the dental ceramics (10). It is reported that composite resins tend to discolor because of extrinsic and intrinsic factors in the oral environment (11,12). Extrinsic factors include staining the material because of absorption or adsorption of colorants from exogenous origin. It is reported that the discoloration varies depending on the oral hygiene and colorant exposure (13,14). Intrinsic discolorations are known to occur depending on material itself, including resin matrix composition, filler particle type and ratio, initiator and inhibitor systems and conversion rate (15).

A significant improvement has been achieved in conversion rate with the use of prefabricated materials for computer aided design/computer aided manufacturing technology (CAD/CAM) systems (15). Since these materials are polymerized industrially under high pressure and temperature, the mechanical and physical properties of the restoration are optimized (16). CAD/CAM systems are becoming an indispensable part of modern dental practice. The manufacturers have developed polymer-based CAD/CAM blocks combining the positive aspects of ceramics such as durability and color stability with the improved flexibility and low abrasiveness of composite resins (17). The polymer-based CAD/CAM blocks consist two groups of materials including hybrid ceramics with a dual network structure of feldspathic ceramic (86%) infiltrated by resin matrix (14%) and resin nano ceramics consisting ceramic particles embedded in a highly cured resin matrix.

Color stability of the restorative materials is getting more important because of majority of patients are expecting color matching restorations. However, there is still lack of information on stainability and changes in translucency of current CAD/CAM blocks. Therefore, the objective of this in vitro study was to evaluate the discoloration susceptibility, translucency change, water solubility, and water sorption of different CAD/CAM blocks after immersion in coffee for one month. The null hypothesis was that there would not be a significant difference in the stainability and translucency changes among the tested materials after the immersion period.

MATERIAL AND METHODS

Four CAD/CAM blocks including Lava Ultimate (LU; 3M ESPE, St. Paul, MN, USA), Shofu Block HC (HC; Shofu Dental GmbH, Kyoto, Japan), Vita Enamic (VE; VITA Zahnfabrik H. Rauter GmbH & Co, Bad Säckingen, Germany), Vita Mark II (VM; VITA Zahnfabrik H. Rauter GmbH & Co, Bad Säckingen, Germany), and one conventional nanocomposite resin restorative (FU; Filtek Ultimate Universal Restorative; 3M ESPE, St. Paul, MN, USA) were tested in the present study. The materials and their compositions are shown in Table 1.

Table 1. Materials used in the study

Material	Type	Composition	Filler Type	Filler
Filtek Ultimate (FU; 3M ESPE, St Paul, MN, USA)	Conventional composite resin	Bis-GMA, UDMA, TEGDMA, PEGDMA, Bis-EMA	20 nm silica particles, 4 - 11 nm zirconium particles.	72.5% by weight
Lava Ultimate (LU; 3M ESPE, St. Paul, MN, USA)	Resin nano ceramic	Bis-GMA, UDMA, Bis-EMA, TEGDMA	SiO_2, ZrO_2, Si/ ZrO_2 cluster	80% by weight
Shofu Block HC (Shofu, Kyoto, Japan)	Resin nano ceramic	UDMA, TEGDMA	Silica powder, micro fumed silica, zirconium silicate	61% by weight
Vita Enamic (VE; VITA Zahnfabrik H. Rauter GmbH & Co, Bad Säckingen, Germany)	Hybrid ceramic	UDMA, TEGDMA	Feldspar ceramic enriched with aluminum oxide	86% by weight
Vita Mark II (VM; VITA Zahnfabrik H. Rauter GmbH & Co, Bad Säckingen, Germany)	Feldspar ceramic	-	Feldspar ceramic	100% by weight

Abbreviations: bisphenol A polyethethylene glycol diether dimethacrylate, Bis-EMA; bisphenol A glycidyl methacrylate, Bis-GMA; poly (ethylene glycol) dimethacrylate, PEGDMA; triethylene glycol dimethacrylate, TEGDMA; urethane dimethacrylate, UDMA.

The sample size was calculated to be 6 samples in each subgroup considering a confidence interval of 0.95, an effect size of 0.93, an alpha of 0.05. The effect size of 0.93 was estimated according to the previous study (18). The power of the present study was determined as 0.95% using G*Power (Heinrich Heine University Dusseldorf, Germany).

A slow-speed precision saw was used for cutting each CAD/CAM block into 2.1-mm-thick specimens under water cooling (n=6). To obtain standardized cylindrical specimens, these slices were marked with a metal mold with an opening in diameter of 10 mm and cut using a diamond bur. The specimens of conventional composite resin were fabricated by condensing the material into a Teflon mold (10 mm in diameter and 2.1 mm in thickness). The mold with composite resin was held between two 1-mm-thick glass slides, which was covered with a polyester strip. The slides were gently pressed together to remove excess composite resin, and specimens were light activated on both sides over glass slide by an LED curing device (Elipar Deep Cure; 3M ESPE, St. Paul, MN, USA) with a light intensity of 1250 mW/cm2 for 20 s. Twelve disk-shaped specimens were fabricated for each material. Afterwards, the surface of all specimens was wet grounded by sanding using silicon carbide papers with descending grits (320, 600, 1200, 2400, 4000) under water cooling for 60 s. The thickness was verified with the digital caliper to obtain a thickness of 2 mm. All samples were ultrasonically cleaned for 10 minutes, and were then placed in distilled water for 24 hours at 37°C.

Specimens were divided into two groups (n = 6) in accordance with the immersion medium and marked to standardize the measurement order. Baseline color measurements were recorded, and specimens were immersed in distilled water and coffee (Nescafé Gold, Single bags; Nestlé, Switzerland). The coffee is prepared by dissolving 2 g sachets in 200 ml of boiling water with no sugar and milk. All samples were immersed in the media for one-month period and the media were renewed daily to eliminate contamination.

The color measurements were performed in accordance with the CIELab system using a clinical spectrophotometer (VITA Easy Shade; VITA Zahnfabrik H. Rauter GmbH & Co, Bad Säckingen, Germany), which has more than 90% reliability and validity (19). All measurements were performed under D65 standard lighting conditions, and the spectrophotometer was calibrated following the manufacturer instructions. The samples were rinsed for 10 s with distilled water and gently wiped dry prior to the measurement. All measurements were recorded against a standard black and standard white backgrounds. The average value of three consecutive measurements was recorded.

A high translucency parameter (TP) value represents low opacity and high translucency (18). TP was calculated by the following equation, which is using the differences in CIELab values (L*, lightness; a*, red/green value; b*, blue/yellow value) recorded against the black (B) and white (W) backgrounds (20):

$$TP=\sqrt{(L_W-L_B)^2+(a_W-a_B)^2+(b_W-b_B)^2}$$

A positive TP difference (ΔTP) values indicate an increase in translucency while a negative ΔTP values indicate a decrease in translucency. The ΔTP was calculated by subtracting TP0 (baseline) from TP1 (one month) (20):

$$\Delta TP = TP1 - TP0.$$

The color difference (ΔE) was calculated by using the following equation:

$$\Delta E=\sqrt{(L_1-L_0)^2+(a_1-a_0)^2+(b_1-b_0)^2}$$

based on the L*, a*, and b* on white background between the same sample before (subscript 0) and after one-month immersion in the staining medium (subscript 1) (15). A high ΔE score represents an excessive color change. The clinically acceptable color change threshold level was defined as ΔE=2.7 with a 50%:50% confidence level (21).

Water solubility and sorption

Water solubility and water sorption were measured by modifying the ISO 4049:2009 from the recommended specimen diameter (15 mm to 13.5 mm) because of the restriction by CAD/CAM blocks dimensions (18). Six cylindrical specimens for each CAD/CAM material were fabricated as 13.5 mm in diameter and 1.1 mm in thickness. The specimens were wet ground on both sides sequentially with silicon carbide paper (320-, 600-, 1200-, 2400-, and 4000-grit) to achieve 1 mm thickness. All specimens were ultrasonically cleaned for 10 minutes and then stored in a desiccator with dehydrated silica gel for 24 hours, then weighed in a digital weighing machine until a stable mass was acquired (m1). Afterwards, samples were stored in distilled water at 37°C for one week. The samples were dried with an absorbent paper and weighed (m2) to calculate water sorption. To calculate water solubility, samples were reconditioned in the desiccator, then weighed until a stable mass is acquired again (m3). The digital caliper was used to measure the diameter and thickness of each specimen to determine its volume (V). The calculations were completed using the equations described below:

Water solubility (μg/mm3) = (m1 − m3) / V

Water sorption (μg/mm3) = (m2 − m3) / V.

Statistical Analysis

The statistical analysis was conducted using a statistical software (SPSS v22.0 for Windows; IBM SPSS Inc., Chicago, IL, USA). The normality of the data distribution was analyzed using the Shapiro-Wilk test. The ΔEs were calculated by two-way ANOVA with material type and immersion media as main factors. Tukey's test was performed for pair-wise comparisons. The ΔTPs, water solubility, and water sorption were analyzed by one-way ANOVA and Tukey's test. A p-value of < 0.05 level was considered statistically significant.

RESULTS

The ΔEs of the four CAD/CAM blocks and conventional resin composite after immersion in the staining solution for one month are depicted in Table 2.

Table 2. ΔE values after immersion in distilled water and coffee for one month

Material	Water	Coffee	p-Value
VMII	0.3 (0.2) ^{B}	1.5 (0.4) ^{C}	0.009
VE	0.6 (0.3) ^{AB}	3.3 (0.6) ^{B}	<0.001
LU	0.9 (0.4) ^{AB}	3.8 (0.7) ^{B}	<0.001
HC	0.9 (0.3) ^{AB}	3.6 (0.6) ^{B}	<0.001
FU	1.5 (0.2) ^{A}	7.3 (1.2) ^{A}	<0.001

Different uppercase letters for each column imply significant difference (p < 0.05).

The two-way ANOVA test results showed that material type and staining solution demonstrated statistically significant influence on the ΔEs ($p < 0.05$). When the ΔEs in tested materials were considered, the tested materials showed significantly different ΔEs in both solutions studied ($p < 0.05$). The discoloration in coffee was significantly higher compared with those in distilled water ($p < 0.05$). The conventional resin composite material FU (7.3) showed the highest discoloration in coffee, followed by polymer-based CAD/CAM blocks (LU, 3.8; HC, 3.6; VE, 3.3). The least discoloration was observed for feldspar ceramic CAD/CAM block VM (1.5). The ΔEs of the specimens were lower than the clinically acceptable threshold ($\Delta E < 2.7$) after the immersion in distilled water for one month. However, the ΔEs of the specimens were higher than the threshold after the immersion in coffee for one month, except VM.

Table 3 exhibits the ΔTP values after coffee or distilled water immersion for one month.

Table 3. ΔTP values after immersion in distilled water and coffee for one month

Material	Water	Coffee	p-Value
VMII	0.0 (0.2) ^{A}	-0.9 (0.1) ^{A}	<0.001
VE	0.0 (0.2) ^{A}	-0.8 (0.1) ^{A}	<0.001
LU	0.2 (0.1) ^{A}	-1.4 (0.4) ^{B}	<0.001
HC	0.1 (0.1) ^{A}	-1.2 (0.3) ^{B}	<0.001
FU	0.1 (0.1) ^{A}	-2.3 (0.2) ^{C}	<0.001

Different uppercase letters for each column imply significant difference ($p < 0.05$).

The ΔTP values after immersion period were ranging from 0.0 to 0.2 and from -2.3 to 0.9, respectively. Two factor ANOVA of ΔTP clearly showed that the two main factors (material type and immersion medium) and their interaction were significant ($p < 0.05$). No significant difference was observed among tested material after immersion in distilled water for one month ($p > 0.05$). The ΔTP values obtained for coffee was significantly greater than those for distilled water ($p < 0.05$). The ΔTP values of tested materials in coffee were significantly different after one-month immersion ($p < 0.001$) and ranked as follows: FU < LU = HC < VM = VE.

The mean water solubility and water sorption values for the tested materials are displayed in Table 4.

Table 4. Water sorption and water solubility after water immersion for 1 week (µg/mm3)

Material	Water sorption	Water solubility
VMII	0.3 (0.2) ^{E}	-0.1 (0.1) ^{C}
VE	10 (0.6) ^{D}	-1.6 (0.1) ^{D}
LU	28.5 (0.7) ^{B}	-0.2 (0.2) ^{C}
HC	35.7 (1.9) ^{A}	0.7 (0.3) ^{B}
FU	25.8 (1.2) ^{C}	1.3 (0.3) ^{A}

The lowest values for water sorption were observed for VM (0.3 µg/mm3), whereas HC exhibited the highest water sorption value (35.7 µg/mm3). VE had the lowest water solubility (-1.5 µg/mm3), followed by LU (-0.2 µg/mm3), VM (-0.1 µg/mm3), HC (0.7 µg/mm3), and FU (1.3 µg/mm3), respectively.

DISCUSSION

The results of the present study revealed that the material type significantly influenced the color and translucency changes. Therefore, the null hypothesis was rejected. Restorative materials are constantly exposed to discoloring effects in the oral environment (22). Previous studies have reported that the color changes of restorative materials depend on factors including diet, presence of microbial dental plaque, and material dependent factors such as hydrophilicity, conversion rate, polishing degree (8,9). It has been reported that the chemical composition of composite resins is directly related to intrinsic discolorations (23). In addition, the discoloration of composite resins is mainly correlated with the resin matrix (4). Reis et al. (24) reported that the increased resin matrix caused greater discoloration, whereas the increased filler ratio, on the contrary, resulted in decreased discoloration.

The effect of the background to be used during color measurement is a controversial issue in the current literature. Both the color of an object and the lighting conditions of the measured surface affect the value to be obtained during the color measurement (12). Since white background is widely used in the studies investigating the color stability of dental materials, white background was preferred in the present study (25). CIELab values are parameters indicating the color and are related to human color perception. The ΔE of the 50:50% perceptibility thresholds, which stands for that half of the observers able to distinguish the color difference between two objects, was 1.2; whereas that of 50:50% acceptability thresholds, which stands for that half of the observers clinically accept the color differences of two objects was 2.7 (18,21). In the present study, the least color change was observed for felspar ceramic CAD/CAM block (VM; $\Delta E = 1.5$) after immersion in coffee for one month, and only this material remained below the clinical acceptability threshold ($\Delta E = 2.7$). On the other hand, the highest color change was observed for conventional nanocomposite resin (FU; $\Delta E = 7.3$) with almost three-fold of the clinical acceptable threshold after one-month immersion in coffee. There was no significant difference among the polymer-based CAD/CAM materials. The polymer-based CAD/CAM blocks exhibited better performance compared with the FU regarding the color change; however, all remained above the clinically acceptable threshold. Considering their composition, resin nano ceramic (LU) and FU both contain the same monomers, and their filler ratios are very close to each other (LU, 80%; FU, 72.5% by weight). However, when comparing the color change values of FU and LU ($\Delta E = 3.8$), the difference between them was found to be almost double. Increased conversion rate due to the industrialized polymerization of LU can be considered as the main reason for this difference.

Among the polymer-based CAD/CAM blocks, hybrid ceramic (VE, ΔE = 3.3) showed the least color change values, whereas LU showed the highest color change values. Arocha et al. (26) evaluated the color stability of various indirect restorative materials. The high color stability of VE can be explained by its filler content (86%). In line with the present study, they reported that LU was more prone to the discoloration compared with other tested materials after one-month immersion in coffee. In a more recent study, Barutcugil et al. (20) evaluated the color and translucency changes of CAD/CAM block materials including LU and VE after exposure to the colorant beverages. The authors reported that VE exhibited higher discoloration in comparison with LU after one-month immersion in coffee. However, LU and VE showed a discoloration above the clinically acceptable threshold because of both the present study and this previous study. Lauvahutanon et al. (18) evaluated the discoloration of various restorative materials after immersion in coffee. After the immersion period, it was reported that there was a discoloration exceeding the clinically acceptable threshold for HC (ΔE = 3.7) and LU (ΔE = 3.6), whereas the discoloration observed for VE (ΔE = 1.4) was below this threshold. Also, no statistically significant difference was found between VE and VM. They also polished restorative materials after the immersion period. After polishing, all CAD/CAM materials, except FU (ΔE = 4.4) showed a discoloration below the clinically acceptable threshold. The variation among studies may be due to differences in study designs. Acar et al. (27) examined the color changes of the three different CAD/CAM blocks after thermal cycle in coffee and reported that VE and LU showed a color change above the acceptable threshold in line with findings of the present study. In a previous study, the color stability and translucency change of LU and VE were investigated by immersing in various staining solutions for seven days (28). They reported that LU and VE had color change values greater than the clinically acceptable threshold, which is supporting the present in vitro study.

Previous studies reported that the 24 hours immersion period corresponds to approximately one month of clinical exposure (29). Therefore, the one-month of immersion would be approximately equivalent to 2.5 years in vivo. After one-month immersion in coffee, the specimens showed pronounced discoloration and reduction in translucency. Discoloration after immersion in distilled water were not evident. The aesthetic appearance of the restorative materials is evaluated not only by color, but also by its translucency. The translucency parameter corresponds directly to the visual assessment of translucency and is determined by calculating the differences in CIELab values measured against the black and white backgrounds (30). Slight increase in ΔTP was observed in resin-based materials (FU, HC, and LU) other than VE and VM after one-month immersion in distilled water. In the present study, all materials exhibited negative ΔTP values after immersion in coffee, and this indicates increased opacity. These findings are consistent with previous studies (18,20).

Previous studies reported that discoloration due to coffee exposure was resulted in both adsorption and absorption of colorants (12). The findings of the present study showed color changes above the clinically acceptable threshold after one-month of immersion for the materials tested, but these values are consistent with the literature (15,18,20,26). The main limitation of the present study was that the specimens were fabricated with certain thickness to ensure standardization of the current study. However, restorations prepared in clinical conditions are not uniform in thicknesses and material thickness may affect color perception. Moreover, these materials are luted to the dental tissues by luting materials that influence the aesthetic outcome. Therefore, clinical studies are needed to evaluate the color stability of CAD/CAM blocks.

CONCLUSION

A discoloration exceeding the clinically acceptable threshold level (ΔE = 2.7) was noticed after immersion in coffee for one month. Furthermore, color and translucency changes were higher in coffee compared to distilled water for all tested CAD/CAM blocks.

Authors's Contributions: Idea/Concept: S.Ş.; Design: S.Ş.; Data Collection and/or Processing: A.T.G.; Analysis and/or Interpretation: S.Ş.; Literature Review: A.T.G.; Writing the Article: A.T.G., S.Ş.; Critical Review: A.T.G.

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