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ORIGINAL RESEARCH ARTICLE

Comparison of Stain Effects of Nicotine and Beverages on Different Cad-Cam Materials

Burak Gökdeniz [1], Gülbike Demirel [2], Ahmet Kürşad Çulhaoğlu [3] and Mehmet Ali Kılıçarslan [4,*]

[1]Clinician, Department of Prosthodontics, Swedish Dental Clinic, Dubai, United Arab Emirates and [2]DDS, PhD, Department of Restorative Dentistry, Faculty of Dentistry, Ankara University, Ankara, Turkey and [3]DDS, PhD, Department of Prosthodontics, Faculty of Dentistry, Kırıkkale University, Kırıkkale, Turkey and [4]DDS, PhD, Department of Prosthodontics, Faculty of Dentistry, Ankara University, Ankara, Turkey & Medical Design Application and Research Center (MEDITAM), Ankara, Turkey

*Corresponding Author; mmkilicarslan@yahoo.com

Abstract

Purpose: This study purposed to compare the effect of smoking cigarettes and drinking beverages and polishing procedures on the discoloration of CAD/CAM materials.
Materials & Methods: Resin nanoceramic (RN: Lava Ultimate), feldspar ceramic (FC: CEREC Blocs Ceramics) and lithium disilicate glass-ceramic (LDC: IPS e.max® CAD) samples (5x5x2 mm) were used for this study. Initially, baseline surface roughness (Ra) and color values (L*, a*, b*) of the samples were measured with profilometer and chroma meter. Then the samples were exposured nicotine, coffee and red wine. The first discoloration values of each sample were measured. Then, all of the samples were subjected to re-polishing procedures. Then, the surface roughness and color values of each sample were measured. The samples were subjected to the same staining process again. After exposure of the samples to the staining agents, the second staining value was measured. Two-way analysis of variance (ANOVA) was used for normally distributed groups, and the Kruskal-Wallis test was used for non-normally distributed groups.
Results: Statistically significant ΔE* values were observed for RN (8.26±1.55) and FC (7.69±1.52) for nicotine in the first staining group. The maximum total color changes were observed in the nicotine group for all of the material samples. Nicotine caused the highest color changes on the test materials than coffee and wine. Surface roughness didn't show a statistically significant difference based on the staining agents for any of the materials within a group ($p<0.05$).
Conclusion: It was observed that nicotine staining is far stronger than beverage staining.

Key words: Color change; dental CAD-CAM materials; polishing; staining effect

Introduction

Nowadays, computer-aided design / computer-aided manufacturing (CAD/CAM) techniques and materials have rapidly gained importance for especially indirect prosthetic restorations.[1] A wide variety of CAD-CAM materials, such as lithium disilicate or resin nanoceramics, can be found for different indications. The success of restorations depends both on mechanical and physical properties, and on the esthetic appearance.[2] Whereas decay is considered a great reason for failure in dental restorations, it seems that anterior restorations have a different failure type compared to posterior restorations.[3] Decay is less present in anterior teeth thus anterior restorations are likely more prone to replacement due to esthetic demands.[4] Almost all restorative materials experience color changes upon exposure to different staining agents.[5–8] Discoloration occurs as a result of either intrinsic (resin matrix) or extrinsic factors (beverages, cigarettes, etc.).[9,10] Additionally, color resistance and vulnerability to various dynamic conditions during usage are crucial for restorative materials. For example, the adjustment and polishing procedures after the cementation of a restoration can remove the glazed or polished layer, exposing the pores of the restorative material and producing a rough surface, which may result in the discoloration of the restoration.[11]

Surface staining of restorations is commonly caused by the penetration of food and beverage pigments into pores at the surface of the material. Numerous in vitro studies have shown that pop-

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ular beverage and food ingredients could cause significant discoloration on the resin-based restorative materials. [5,10] Additionally, the effects of staining agents in cigarettes on staining must not be ignored. However, there are only a few studies about the effect of smoking on the staining and surface roughness of restorative materials. [8,10,12,13]

The objective of this study was to discuss the effects of commonly used extrinsic staining agents on the surface roughness and staining of three different ceramic-based dental materials. The null hypotheses of present study were that contamination of beverages and smoking would show similar effect to stainability of the restorative materials and the type of dental material would not affect the discoloration amount of the restorative materials.

Materials and Methods

Three different CAD-CAM materials, a Resin nanoceramic (RN: Lava Ultimate, 3M ESPE, St. Paul, MN, USA), a Feldspar ceramic (FC: Cerec Blocks, VITA Zahnfabrik, Bad Säckingen, Germany,) and a Lithium disilicate glass-ceramic (LDC: IPS e.max CAD, Ivoclar Vivadent AG, Schaan, Liechtenstein) were prepared (N=36 per group) to test their color stability against cigarette smoke, coffee and red wine (Table 1).

The CAD/CAM blocks were sliced with a low-speed cutting wheel (Micracut 201, Metkon, Turkey) into samples of 5 mm edge length and 2 mm thickness, under water-cooling. The sectioned slices were polished with 600, 800, 1200 grit silicon carbide abrasive papers (P1000-P4000Metkon, Gripo 2v Grinder-Polisher, Turkey). [9] The final thicknesses of each sample were measured with a digital micrometer (Mitutoyo, Kawasaki, Japan). The prepared samples were stored in distilled water at 37 °C for 24 hours. The baseline surface roughness (Ra) values of all of the samples were measured with a profilometer (Perthometer M2; Mahr GmbH) before discoloration. Additionally, the baseline pre-staining color score of each sample (L0*, a0*, b0*) was measured using a chroma meter (CR-321; Minolta Inc). [5] The chroma meter was calibrated with a white standard calibration plate according to the manufacturer's instructions before each measurement. All of the measurements were made in a box with a 65-K daylight fluorescent lamp with an intensity of 18 W to standardize the external lighting according to CIE standards. The head of the colorimeter (Ø4.30 mm) was placed on the middle of each sample using a custom-fabricated Teflon holder to ensure the same localization of each sample for accurate measurement. [5] Three consecutive measurements were implemented on each sample to correct for bench errors and to record the average values for both the roughness and color test. The scores obtained by the chroma meter were evaluated according to the CIE Lab system as three coordinates (L*, a*, b*) to describe the color of an object within a three-dimensional color space.

Table 1. Experimental CAD-CAM material information.

Material Brands	Composition	Manufacturer	Lot Number
LavaTM Ultimate	Resin nanoceramic	3M ESPE, St. Paul, MN, USA	N531779
CEREC Blocs Ceramics	Feldspar ceramic	VITA Zahnfabrik, Bad Säckingen, Germany	32080
IPS e.max® CAD	Lithium disilicate glass-ceramic	Ivoclar Vivadent AG, Schaan, Liechtenstein	R51558

Each CAD/CAM block group was subdivided into 3 equal subgroups (n=12) according to the staining protocols: cigarette smoke, coffee and red wine. [9] One of these groups per material was subjected to a smoke nicotine staining process (N) in a custom-made cigarette smoke container. The volume of the smoke container apparatus was designed to simulate in vitro the oral cavity of smokers (approximately 70 cm3). The samples were attached to the sample container of the apparatus with white adhesive pads (Patafix; UHU GmbH) so that only visible contact surfaces were exposed to cigarette smoke. The materials in the second group were immersed into coffee (C) to measure the staining potential of the hot beverage. The final group was kept in red wine (W) at room temperature. The dosage calculations of the staining agents were set considering the assumptions that a person with a habit will be exposed to a staining agent at least once a day for a year. The test amount of the cigarette for annual consumption was determined using the following formula:

Amount of cigarette needed to simulate the active exposure time of annual cigarette consumption = [(Number of active aspirations of a cigarette X Length of time each inhalation stays in the mouth X Number of days in a year) + Neutralization time of each cigarette with saliva for a year (365X60)] / Passive smoke time of a cigarette (600 seconds)

[(15 × 7 × 365) + 21900] / 600 = 100 cigarettes

For nicotine group, 100 cigarettes (Tekel 2001; British American Tobacco, Samsun, Turkey) were used. The test time was set to last 10 minutes to simulate smoking for each cigarette using a smoke container to simulate in vitro the oral cavity conditions of a smoker.

The act of beverage exposure in the oral cavity was simulated at the point of the active contact time of the beverage. According to this approach, one small cup of coffee or a glass of wine (200 ml) will require approximately 11 sips. One sip of the beverage stays an average of 3 seconds in the mouth. The test time of each beverage for annual active consumption was therefore determined using the following formula:

Time needed to simulate the active exposure time of annual coffee/wine consumption = (Number of sips of 200 ml fluid X Time of stay of each sip in the mouth X Number of days in a year) + Neutralization time of each beverage with saliva for a year (365X60)

[(11 X 3 X 365) + 21900] = 33945 seconds = 565.75 minutes = 9.43 hours

Coffee was prepared by mixing 2 g of coffee (NESCAFÉ Classic; Nestlé India Limited PB, Gurgaon, India) and 200 ml of hot water according to the manufacturer's instructions. The samples were transferred to a glass vessel using the same adhesive pads and were immersed in a magnetic stirrer that was filled with coffee solution at 55 °C; the solutions were stirred at 100 rpm for 10 hours.

Red wine-exposed samples were stored on the same magnetic stirrer with 200 ml of red wine at room temperature (22±2 °C) and at the same mixture speed of coffee group (Vintura, Ankara University Faculty of Agriculture, Ankara, Turkey). Each group immersed fresh and separated solutions. After the samples were exposed to the staining agents, the samples were kept in distilled water for 5 minutes. The first staining score of each sample (L1*, a1*, b1*) was measured using the same measurement technique.

After obtaining the first staining scores, all of the samples were polished by using a contra-angle micro-motor handpiece and polishing brushes. For this purpose, each test sample was polished for 30 seconds at 10,000 rpm by using polishing brushes and a fluoride-free polishing paste (TDV Poligloss; TDVDental Ltda., Premedore, Brazil). The polished samples were rinsed with distilled water, dried and submitted for second color assessments to derive the L2*, a2*, b2* values after brushing. The surface roughness (Ra) values of each sample were measured three times using the same profilometer before re-exposure to the staining agents to measure the effect of cleaning on the surface texture of the tested materials.

The samples were subjected to the same staining process again. After the second exposure to the staining agents, all of the samples

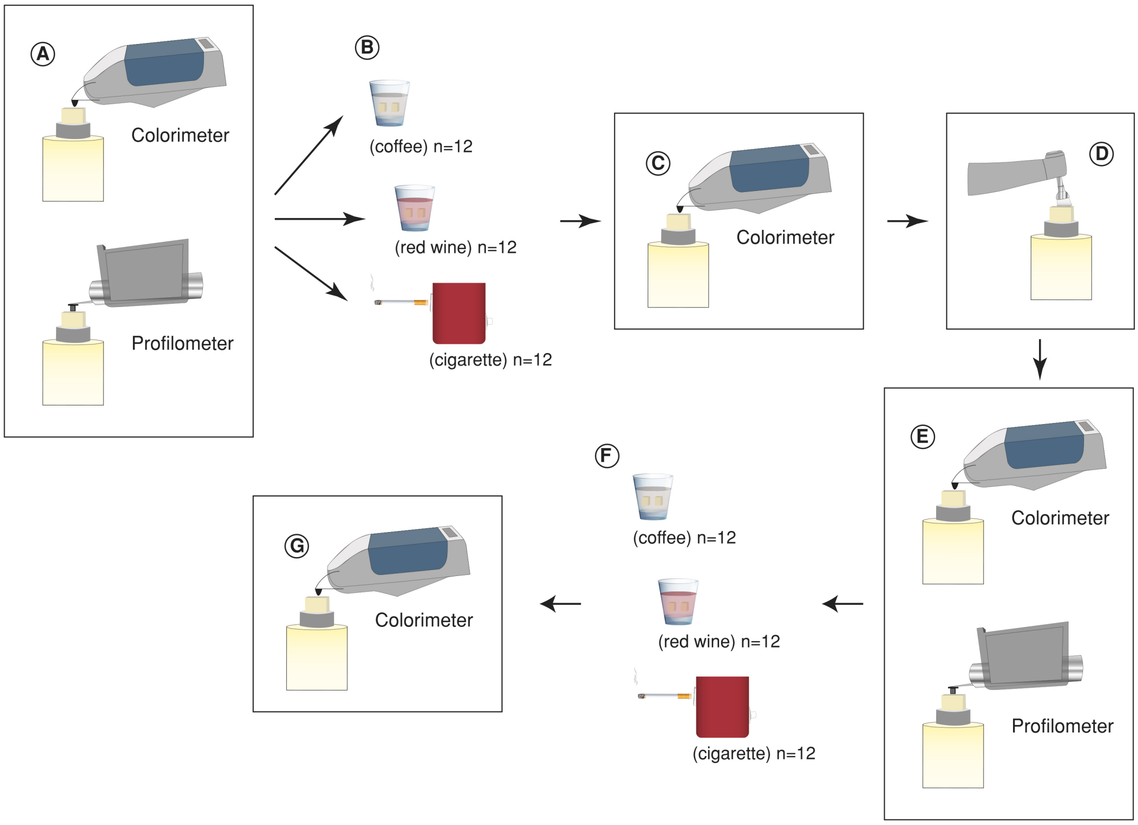

Figure 1. The experimental workflow. A: Baseline color and surface roughness measurement of all samples. B: The samples were randomly divided into three groups and exposed to staining agents. C: Second color measurement of all samples. D: All the samples were subjected to re-polishing procedures. E: Third color and second roughness measurements of all samples. F: The samples were exposed to staining agents for a second time. G: The final color measurements of all samples.

were rinsed with distilled water, and the second staining values (L_3^*, a_3^*, b_3^*) were measured using the same measuring technique. All of the measurements were recorded by the same observer (Figure 1).

The total color changes (ΔE^*) between the color positions were derived using 3-dimensional L^*, a^*, b^* and the following formula:[7]
$\Delta E^* = [(\Delta L^*)2 + (\Delta a^*) 2 + (\Delta b^*)2]$ ½

Statistical analyses were conducted using statistical software (IBM SPSS Statistics Version 21). To analyze the color differences between groups, two-way analysis of variance (ANOVA) was used for normally distributed groups, and the Kruskal-Wallis test was used for non-normally distributed groups. According to assumption of the homogeneity of variance, post hoc Tukey's and the Tamhane T2 multiple comparison tests were used. The data analyses were evaluated at a significance level of $p<0.05$ for all of the tests. Surface roughness data were analyzed using the same statistical software via the same tests. Finally, the correlation coefficients between the surface roughness and results of the discoloration test was determined for each sample using Pearson's rank correlation at the $p<0.05$ significance level.

Results

Comparing the staining agents in each material, in the first time, there was statistically significant difference between RN and FC materials exposed to N ($p <0.05$). There were statistically significant differences between N and the other staining agents at the RN and FC materials for the ΔE^* parameter ($p <0.05$). The most significant total color changes were between with N for RN ($p <0.05$). Additionally, RN showed the most significant total color change at

Table 2. Descriptive Statistics of ΔE^*value of test materials for initial staining ($p< 0.05$).

Test group (n=12)		Mean ± SD	Min	Max	95% CI
RN	N	8.26 ± 1.55*	6.23	10.97	7.28 - 9.24
	C	1.94 ± 0.90**	0.79	3.20	1.36 - 2.51
	W	3.15 ± 0.88**	2.11	5.13	2.59 - 3.71
FC	N	7.69 ± 1.52†	6.00	10.42	6.73 - 8.66
	C	2.01 ± 0.51††	1.17	2.83	1.68 - 2.33
	W	1.71 ± 0.62††	0.51	2.89	1.31 - 2.11
LDC	N	3.67 ± 2.09·	1.02	7.51	2.34 - 5.00
	C	2.22 ± 1.27·	0.77	4.52	1.41 - 3.02
	W	2.80 ± 0.68·	1.87	3.91	2.36 - 3.23

* Refers statistical differences for RN groups.
† Refers statistical differences for FC groups.
· Refers statistical differences for LDC groups.
There is statistical difference between single symbol and couple symbol for each material group.

W ($p <0.05$) (Table 2). Considering the second staining procedure, the maximum total color change was in the N group for all of the material samples ($p <0.05$). There was a statistically significant difference among materials that underwent N exposure and C immersion ($p <0.05$), but there was no significant difference among the materials immersed in W($p >0.05$). RN was the most affected material when immersed in C ($p <0.05$) (Table 3).

When the cleaned samples were analyzed, there was a significant difference between the material groups before and after the cleaning procedure for all of the staining agent effects ($p <0.05$). However, there was no significant difference between the ΔE parameters for the FC and LDC samples for different staining agents

Table 3. Descriptive Statistics of ΔE*value of test materials between initial and second staining ($p< 0.05$).

Test group (n=12)		Mean ± SD	Min	Max	95% CI
RN	N	16.58 ± 3.16*	10.82	21.85	14.57 - 18.59
	C	4.27 ± 1.20 **	2.78	6.09	3.50 - 5.03
	W	3.16 ± 1.02 **	1.00	4.22	2.51 - 3.80
FC	N	10.90 ± 1.94†	7.53	13.92	9.66 - 12.13
	C	2.21 ± 0.74 ††	1.00	3.79	1.74 - 2.68
	W	4.47 ± 1.34 ††	2.09	6.79	3.61 - 5.32
LDC	N	15.14 ± 1.76•	12.32	18.44	14.02 - 16.25
	C	2.57 ± 0.64 ••	0.82	3.42	2.16 - 2.97
	W	3.69 ± 1.77 ••	1.98	7.20	2.56 - 4.81

* Refers statistical differences for RN groups.
† Refers statistical differences for FC groups.
· Refers statistical differences for LDC groups.
There is statistical difference between single symbol and couple symbol for each material group.

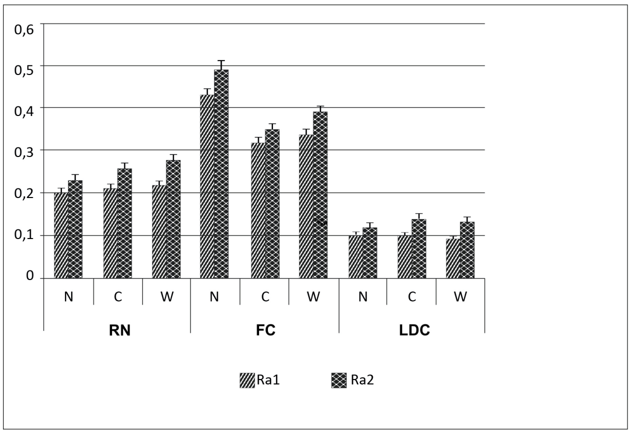

Figure 2. The first (Ra1) and second (Ra2) surface roughness values of the samples (μm).

Table 4. Descriptive Statistics of ΔE*value of test materials between initial and cleaning status ($p< 0.05$).

Test group (n=12)		Mean ± SD	Min	Max	95% CI
RN	N	1.09 ± 0.44*	0.57	1.92	0.81 - 1.38
	C	1.67 ± 0.54 **	0.54	2.39	1.33 - 2.01
	W	1.85 ± 0.44 **	0.99	2.51	1.57 - 2.13
FC	N	1.36 ± 0.68 †	0.28	2.07	0.92 - 1.80
	C	1.14 ± 0.69 †	0.33	2.80	0.70 - 1.58
	W	0.85 ± 0.45 †	0.35	1.63	0.56 - 1.13
LDC	N	3.23 ± 0.90•	2.29	5.39	2.66 - 3.80
	C	1.43 ± 0.51 •	0.36	2.02	1.10 - 1.75
	W	2.84 ± 0.45 •	2.16	3.62	2.56 - 3.13

* Refers statistical differences for RN groups.
† Refers statistical differences for FC groups.
· Refers statistical differences for LDC groups.
There is statistical difference between single symbol and couple symbol for each material group.

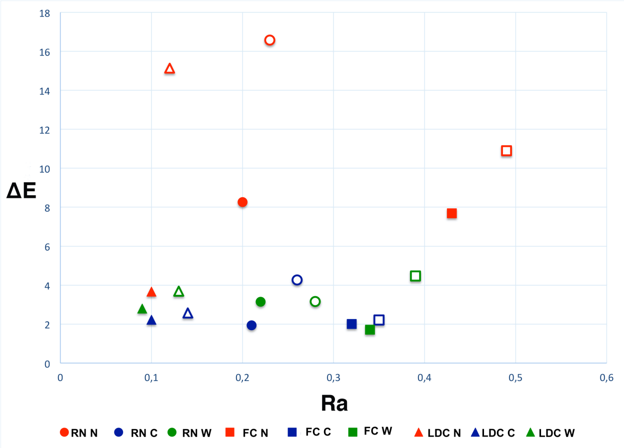

Figure 3. Figure shows the relationship between the baseline and final ΔE and Ra values. Filled shapes refer to baseline measurements and null shapes refer to final measurements.

($p >0.05$). When N-exposed and C-immersed samples were cleaned, the ΔE* values of LDC were significantly higher than those of the other materials ($p <0.05$). On the other hand, FC showed significantly lower values than RN and LDC when the W-immersed samples were cleaned ($p <0.05$). When the RN group samples were analyzed, there was a significant difference between the N and C or W parameters in the RN group ($p <0.05$). Although all of the staining agents showed similar cleanability, S-exposed RN was more cleanable than the other materials. When the cleanability of all of the groups was evaluated, FC immersed in W showed a lower ΔE* value, indicating it was the best-cleansed sample ($p <0.05$). (Table 4).

LDC demonstrated the lowest Ra (0.09 ± 0.04 μm), and FC showed the highest roughness (0.43 ± 0.24 μm) before cleaning. Although there were statistically significant differences between materials, statistically significant differences were not occurred at the same staining agent subgroups between before and after cleaning for all of the materials. When the roughness of the materials were observed after the cleaning procedure, FC showed the highest roughness (0.49 ± 0.22 μm), and LDC showed the lowest roughness (0.12 ± 0.03 μm) for all staining agents after cleaning (Figure 2).

The correlation coefficient between the surface roughness and the results of the discoloration test were determined for each sample using the Pearson rank correlation test at the $p<0.05$ significance level. The results of the Pearson rank correlation test indicated that a statistically significant correlation was found between the Ra and Δ values both first and second Ra values and ΔE values ($P < 0.05$, r2 = 0.62), indicating that these two variables were correlated at 62% with each other. According to the evaluation, a positive correlation was determined between the roughness values and the N and C staining agents for FC initially (Figure 3).

Discussion

In the present study, the effect of cigarette smoke and two other beverages on the discoloration and surface roughness of three different CAD/CAM materials was analyzed. Thenull hypotheses of this study were rejected because the staining agent type and type of restorative material had a significant effect on color change. However, polishing of the sample was the determinant factor for these alterations.

Strength for discoloration is a crucial variable that must be evaluated when choosing a material, and color stability may be of common importance to operators and patients especially in the esthetic zone. There have been many investigations and comparisons in the dentistry literature concerning the coloration characteristics of dental compounds. A common reason for surface staining is the penetrative effect of staining agents in foods, beverages identified in previous studies.[7,14] However, there are few studies concerning the optical and esthetic effects of nicotine addiction and smoking habits on restorative materials.[8,10,12,13] Thus, it is a fact that staining is the most significant effect of a smoking habit on the enamel surface and on oral esthetics. Nicotine usage, especially smoking, is a frequent health problem. Therefore, this study also purposed to evaluate the effects of nicotine on the color stability and surface features of dental materials.[15]

The ability to clean the superficial staining from the esthetic materials and the relationship between the surface roughness and staining effect were studied after fabrication and prophylaxis. It is important to obtain sufficient polishing because otherwise, it may result in residual surface roughness, thus increasing staining agent adherence and changing the mechanical and esthetic characteristics of the materials. Gönülol and Yılmaz predict that surface processes are as important as structural specifications of the restorative materials regarding the staining levels and final polishing procedures may also affect surface roughness, which is related to early discoloration.[16] A rough surface mechanically retains surface stains better than a smooth surface. Additionally, the results of the present study showed that surface stain ability is correlated with the surface texture of the material, and more resistant materials, such as lithium disilicate glass ceramics, attained significantly lower surface roughness and color change values than the other materials. Furthermore, minor topographical changes were observed with the LDC material after prophylactic procedures. In this study, discolorations below or above $\Delta E^*=3.3$ were referred to as "acceptable" or "unacceptable", respectively.[15–17] According to the present study, although all materials showed "acceptable limitations" of color changes for the beverages, they showed "unacceptable" color changes for the nicotine groups after the first staining stage. There was a significant increase in staining for all materials with all coloring agents on the second staining process after the cleaning. The most obvious total color changes were observed for the N-exposed RN material for both staining processes. The highest total color changes were observed in the N group for all material samples (16.58 for RN, 15.14 for LDC and 10.90 FC respectively) after the second staining procedure. It was observed that nicotine generally produced significantly higher color change compared with the other tested beverages.

Ren et al. reported that although the static immersion of composite material into coffee caused adsorption of staining agent onto the composite surface, which can be easily removed through a mechanical process such as ultrasonic cleaning or brushing, absorption of staining agent into a resin matrix has more importance because mechanical cleaning will be ineffective, and the replacement of the restoration is generally needed.[18] Additionally, it was reported that although all of the materials were based on composites, each material has a different affinity toward the pigmentation agents. Kursoglu et al. defined the similar findings as in the present study by assessing the coloration between specific surface topographies and coffee staining. A positive significant relationship was detected between Ra and ΔE.[11]

Alandia-Roman et al. investigated the staining effect of cigarettes on dental materials in relation to surface cleaning.[10] That study,nicotine staining evaluated only at the end of the experiment and researchers concluded that among the all tested samples, even glazed samples, were stained to clinically unacceptable levels, and the glazing process decrease the surface roughness of all of the samples. The first study was managed by Raptis et al. who found significant differences in the color stability of composites continuously presented to the smoke from 40 cigarettes.[19] Recent studies have compared the effect of nicotine with alcoholic beverages and have shown that the cooperation of these two agents could potentiate the discoloration of the restorative materials. When the nicotine comes into contact with the tooth, and the restoration of the surface esthetics is set to a great extent; the teeth of the smoking individual become yellowed or even blackened due to saturation by contaminants from the smoking.[15] Exposure to cigarette smoke caused the discoloration of the enamel surface in the range of 4.4 ΔE, which is considered to be a clinically unacceptable result. These changes are consistent with those of other studies, which reported that staining caused by smoking was higher than that caused by other types of staining agents.[8,10,12] Comparing the effects of different beverages, it was observed that coffee generally produced the worst stains, followed by red wine for all tested materials. This might be due to the variation in colorants and the pH values present in the two beverages. Result of the effects of different beverages corroborated with prior literature.[7,20]

In this study, the goal was to determine the effects and cleanability of consumed staining agents based on the annual minimum consuming period standards. Contemporary CAD-CAM materials were used. Similar to the work of Acar et al. in the present study, it was observed that a resin hybrid materials was more vulnerable to staining than a lithium disilicate material, especially within the situation of alteration by polishing on the factory-made surface characteristics.[9,21] Hybrid CAD/CAM materials are formed predominantly (> 50% by weight) of refractory inorganic compounds, regardless of the presence of a less predominant organic phase (polymer).[22] By overlooking the simulation limitations of the in vitro conditions, the obtained results show a resemblance to the abovementioned experiments, and it was observed that there is a correlation between the surface roughness and the staining ratios.

The limitation of this investigation is that it was an in vitro study to allow for discoloration on both parts of the samples. However, in clinical conditions, the material is bonded to a tooth structure and is exposed to staining agents on only one side. The results of this study should be confirmed with clinical studies.

Conclusion

Within the limitations of the present study, it was concluded that:

- Dietary and habitual factors caused the staining of the test materials. However, nicotine has a far stronger effect than liquid staining agents in the staining process.
- It was observed that a high level of structural resistance of the material and low surface roughness values decreased the superficial staining effects.
- The increase in the surface roughness increased the nicotine-based staining the most.

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Author Contributions

B.G.: Proposing the study, manufacturing of samples, and writing of introduction G.D.: Performing of color tests and optical analyses, the conduct of the statistical analyses A.K.C.: Design of the study, writing of material methods and results M.A.K.: Design of the study, performing the contamination of samples, and writing discussion

Conflict of Interest

Authors declare that they have no conflict of interest.

Authors' ORCID(s)

B.G. 0000-0002-8640-7260
G.D. 0000-0002-0828-0532
A.K.C. 0000-0002-2396-2355
M.A.K. 0000-0002-8619-957X

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