Yılmaz et al. BMC Oral Health (2024) 24:1104
https://doi.org/10.1186/s12903-024-04895-2

RESEARCH

Open Access

Effect of immune-boosting beverage, energy beverage, hydrogen peroxide superior, polishing methods and fine-grained dental prophylaxis paste on color of CAD-CAM restorative materials

Kerem Yılmaz[1*], Erdem Özdemir[2] and Fehmi Gönüldaş[3]

Abstract

Background The effect of an immune-boosting beverage (SAM) containing Sambucus Nigra, an energy beverage (ENE), an in-office bleaching (BLE) agent with 25% hydrogen peroxide superior, glazing (GLA) or polishing (POL) methods, and professional dental prophylaxis (PDP) on the color of CAD-CAM restorative materials is unknown.

Methods In total 210 specimens were prepared, consisting of CAD-CAM feldspathic (FC), zirconia-reinforced lithium disilicate ceramic (ZLS) and hybrid ceramic (HC). The ceramic specimens were divided according to the polishing methods of glazing (GLA) and mechanical polishing (POL). All materials were divided into two groups: with and without BLE. A 25% hydrogen peroxide superior (HPS) gel was used for BLE. After the baseline (BAS) measurement, the specimens were immersed in 3 different beverages (distilled water (DIS), SAM, ENE). After 28 days, a fine-grained (RDA 7) prophylaxis paste was applied. Statistical analysis of ΔE00 color difference values was performed by 3-way ANOVA and Bonferroni test ($\alpha = 0.05$).

Results The effect of all other actions except material-BLE-beverage on color for BAS-Day 28 was statistically different ($p < 0.05$). The effect of material, material-BLE, beverage on color for Day 28-PDP was statistically different ($p < 0.05$). After 28 days, the lowest color change was found in FC-GLA and HC immersed in DIS ($p = 0.0001$) and the highest in FC-POL immersed in ENE ($p = 0.0002$). PDP was efficient in color recovery in HC immersed to DIS, ENE and SAM ($p = 0.0010$). For FC, HC and ZLS, BLE caused a higher color change ($p < 0.0001$). Regardless of the material, the highest color change for BLE-beverage was found in BLE-treated specimens immersed in ENE ($p = 0.0496$) and the lowest color change was found in non-BLE-treated specimens immersed in SAM ($p = 0.0074$).

Conclusions In materials pre-exposed to 25% HPS, the effect of PDP on color recovery was lower than in unexposed materials. After 28 days, mechanical polishing produced higher color change in FC than glazing, however, in ZLS effects of glazing and mechanical polishing on color were similar. For material/polishing method, HC was the most

*Correspondence:
Kerem Yılmaz
drkeremy@hotmail.com

Full list of author information is available at the end of the article

effective. ENE caused higher color change than DIS and SAM. PDP was more effective than ENE in restoring color to DIS- and SAM-immersed specimens.

Keywords Covid-19 pandemic, CAD-CAM hybrid, Zirconia-reinforced lithium disilicate, Feldspathic ceramic, Office bleaching, Dental prophylaxis, Glazing, Hydrogen peroxide, Beverage, Sambucus Nigra

Background

Dental restorations performed in regions where appearance is crucial should keep their physical properties long-term. Restorative materials made by computer-aided design and computer-aided manufacturing (CAD-CAM) are frequently preferred for this purpose today. These types of materials may be glass ceramic, zirconium or resin based [1].

Feldspathic ceramics (FC) have a glassy structure containing a crystalline phase. In lithium disilicate ceramics, the metasilicate phase transforms into stronger disilicate phase by crystallization. Nowadays, zirconia-reinforced lithium disilicate ceramics (ZLS) have been developed [2]. One of the new developed materials is hybrid ceramics (HC), which contain dimethacrylate polymers and have a binary network structure [3].

While the smoothness of the surfaces of CAD-CAM ceramic materials can be performed by both glazing (GLA) and mechanical polishing (POL), GLA is not possible in resin-containing ceramics due to the loss of the organic matrix in firing [4]. On smoother surfaces, there would be less absorption of beverage-induced pigments to the material surface and consequently less discoloration would occur [5].

During the dental bleaching (BLE) process, when the BLE agent contacts the restoration surface, the existing physical features may change. BLE agents currently contain varying concentrations of carbamide peroxide (CP) or hydrogen peroxide (HP): 30–35% HP is usually used for in-office techniques, while 10–16% CP is commonly used at home [6]. In studies examining the effects of BLE with CP or HP on the restorative material, it was reported that BLE agents would degrade the surface integrity of the material by dissolving in the restorative material [7]. Nowadays, new BLE agents with different components have been developed and it is necessary to perform new studies to investigate the performance of these agents. The one of them is an office BLE agent containing 25% HP superior (HPS) [8].

Restorations discolored by beverages are polished regularly by clinicians to correct the color change of restorations and to remove dental plaque. Current knowledge about professional dental prophylaxis (PDP), which is one of the methods applied for this purpose, is inadequate [9]. In recent years, various PDP pastes have been introduced to the market and there is a need for current research on these pastes with abrasives with low relative dentin abrasiveness (RDA) [10].

Studies examining the effect of beverages on the color of restorative materials have mostly focused on beverages such as tea, coffee, cola and wine [5]. After the Covid-19 pandemic, people's consumption habits have changed and as a result, the consumption of energy beverages has increased [11]. Therefore, it is necessary to investigate the effect of energy beverages on the color of CAD-CAM restorative materials. Another beverage with increasing consumption is black elderberry (Sambucus Nigra). This beverage, which is used as a treatment support in the Covid-19 pandemic, may change the color of dental materials because it contains anthocyanin [12]. There is no study on the effect of beverage with Sambucus Nigra on the color of CAD-CAM ceramic or hybrid ceramic materials. There are several studies [9, 13, 14] examining the effect of polishing methods, BLE or PDP on the color of CAD-CAM restorative materials, but no study has examined these variables together. For these reasons, the aim of this study was to evaluate the effect of energy beverage and immune-boosting beverage with Sambucus Nigra, in-office BLE with HPS and PDP on color of CAD-CAM FC, ZLS and HC. The null hypotheses were that (i) material/polishing method, BLE, beverages would have no effect on the color of tested materials and (ii) PDP would have no effect on the color recovery of discolored materials.

Methods

The materials used and the study design are displayed in Table 1 and in Fig. 1, respectively. Using a diamond saw cutting machine (Micracut 201, Metkon, Turkey), 2 mm thick rectangular shaped specimens were obtained from FC, ZLS and HC blocks. Specimen size calculation was performed using a statistical power analysis program (G*Power ver. 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Germany) to determine a significant group effect. In the analysis, 30 treatment combinations and 2 factors were considered. Adjusting for significance level (alpha) 0.05, power 0.80 and medium effect size (partial eta squared) 0.06 (corresponding to Cohen's d effect size 0.2526), the minimum specimen size was calculated as 158. To make the study more powered, the number of specimens in each treatment group was determined as 7 and therefore the total number of specimen was determined as 210 [15, 16].

A total of 84 FC specimens were equally divided into two groups according to the polishing method (GLA or POL). A total of 84 ZLS specimens were also divided into

Table 1 Materials tested in the study

Material	Code	Type	Composition	Manufacturer
Cerec C	FC	Feldspathic glass matrix ceramic	56–64% SiO_2, 20–23% Al_2O_3, 6–9% Na_2O, 6–8% K_2O	Sirona Dental, Beinsheim, Germany
Vita Suprinity	ZLS	Zirconia-reinforced lithium silicate ceramic	56-64% SiO_2, 1-4% Al_2O_3, 15-22% Li_2O, 8-12% ZrO_2, 1-4% K_2O (~0.5 µm)	VITA Zahnfabrik, Bad Sackingen, Germany
Vita Enamic	HC	Polymer-infiltrated ceramic network	86% inorganic (58–63% SiO_2, 20–23% Al_2O_3, 6–11% Na_2O, 4–6% K_2O, 0.5–2% B_2O_3), 11–14% organic (methacrylate polymer, UDMA, TEGDMA)	VITA Zahnfabrik, Bad Sackingen, Germany
Cavex Bite&White In-Office	BLE	Office bleaching gel	25% hydrogen peroxide superior, thickeners, pH regulators, reversible poloxamer, glycerine	Cavex Holland BV, Haarlem, Netherlands
Red Bull	ENE	Energizing beverage	Glucose, citric acid, carbodioxide, sodium bicarbonate, taurine, caffeine, plain caramel, riboflavin, vitamins B3, B5, B6, B12	Red Bull GmbH, Salzburg, Austria
Sambucol Plus Effervescent Tablet	SAM	Immune-boosting beverage with black elderberry	Black elderberry extract, citric acid, sodium hydrogen carbonate, L-ascorbic acid, zinc	Pharmacare Europe, UK
Proxyt Fine	PDP	Fine-grain professional prophylaxis paste	Silica (RDA 7 size particles), water, glycerine, sorbite, xylit, anorganic fillers, natrium-fluoride, flavor and pigments	Ivoclar Vivadent, Schaan, Liechtenstein

two groups in the same way. These groups were further divided into two more groups of equal numbers, with and without prior BLE. A total of 42 HC specimens were prepared and divided into two groups of equal numbers, one with and without prior BLE.

FC-GLA and ZLS-GLA specimens were glazed using appropriate glaze powder and liquid (Vita Akzent Plus, VITA Zahnfabrik, Germany) in accordance with the manufacturer's recommendations. The HC specimens were only mechanically polished due to the microstructural limitation of containing resin content [4]. FC-POL,

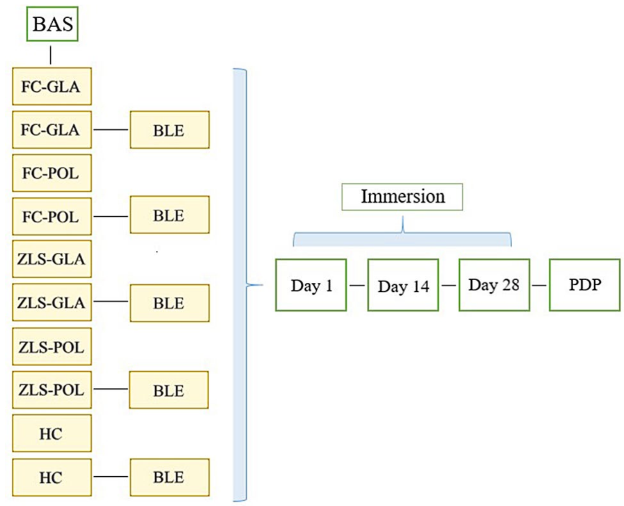

Fig. 1 Design of the study

ZLS-POL and HC specimens were polished with a ceramic polishing set (Diasynt Plus HP, EVE Ernst Vetter, Germany). In order to simulate intraoral conditions, only one side of the specimens was polished. Thickness of the specimens was controlled by digital micrometer (Absolute Digimatic Caliper, Mitutoyo, Japan) and then the specimens were placed in an incubator (UM 400, Memmert, Germany) in distilled water at 37 °C for 24 h to standardize the ambient conditions prior to BLE.

Baseline color measurements (BAS) were taken in all specimens, and then a 25% HPS agent (Cavex Bite&White In-Office, Cavex Holland BV, Netherlands) was applied in the FC-GLA-BLE, FC-POL-BLE, ZLS-GLA-BLE, ZLS-POL-BLE and HC-BLE groups. For this purpose, the gel was applied to specimen surface with an applicator at a thickness of approximately 1 mm. In the instructions for use, the manufacturer recommends "to be applied for 10 to 15 minutes and 2 to 3 times a day", however, since there is no definite directive in this recommendation and considering the possible limitations of in vitro laboratory conditions, the total time was determined as 60 min. After BLE, the specimens were washed, rinsed and measurements were taken [17].

Each specimen was kept in its own 10 ml container throughout the process. According to the manufacturers, the average consumption time for beverages such as tea or coffee are 15 min. In this case, 24 h of storage in the beverage is roughly 1 month of consumption. To simulate a period of 2.5 years, a 28-day immersion period was applied, and color measurements were taken on the 1st, 14th and 28th days [18].

After immersion process, the specimens were washed, dried and then started to PDP. For this purpose, a dental contra-angle angldruva (CrossPro, Anthogyr SA, France) operating at 16:1 speed was used and the rotational speed was set to 2500 rpm. A fine-particle prophylaxis paste

(Proxyt Fine, Ivoclar Vivadent, Germany) was used as a paste. For each specimen, 0.05 mL of paste was applied to the specimen surface and POL was performed. PDP is performed 4 times a year and takes approximately 20 s to remove one side of a tooth. Therefore, PDP was performed for 1.5 min in each specimen to simulate a 1-year prophylaxis [19]. After PDP, color measurements were taken.

All color measurements were done in a custom made color booth to standardize the environmental conditions during measurements and to prevent the ambient light from causing errors in color measurements [20]. The inside of the booth prepared in dimensions of 30 cm × 130 cm × 70 cm was covered with neutral gray background cardboard [21]. The booth had a daylight-imitating lamp (Philips Master TL-D 90 De Luxe 18 W/965 1SL 65000 K, Eindhoven, Netherlands) and was in a dark room. Color measurements were performed on the center of the specimens with a spectrophotometer (Vita Easyshade V, VITA Zahnfabrik, Germany). The spectrophotometer gives the three-dimensional color values of Commission Internationale de l'Eclairage (CIE) L* (lightness), a* (red-green) and b* (blue-yellow). The magnitude of the color change was calculated using the following formula [22]:

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

Statistical analysis was performed with a statistical software package (Statistical Analysis Software SAS 9.4, SAS Institute, USA). For the analysis of discoloration values, 3-way ANOVA test were applied. Bonferroni corrected post-hoc test were used if a significant mean difference was found in any of these two independent variables. Cohen d post-power test, was applied to determine the effect size of the analyses ($\alpha = 0.05$).

Results

Results of 3-way ANOVA for color change values are shown in Table 2. The effect of all other actions except material-BLE-beverage on color for BAS-Day 28 was statistically different ($p<0.05$). The effect of material, material-BLE, beverage on color for Day 28-PDP was statistically different ($p<0.05$).

The results of the Bonferroni test for beverage-material are in Table 3. For BAS-Day 1, the lowest color change was in the HC immersed in DIS and the highest color change was in ZLS-GLA immersed in DIS ($\Delta E_{00}=2.6$, $p=0.0001$). For BAS-Day 14, the lowest color change was in HC immersed in SAM ($\Delta E_{00}=0.9$, $p=0.0015$) and the highest color change was in ZLS-GLA immersed in SAM ($\Delta E_{00}=2.3$, $p=0.0015$). For BAS-Day 28, the lowest color change was in HC immersed in DIS ($\Delta E_{00}=1.3$, $p=0.0001$) and the highest color change was in FC-POL immersed in ENE ($\Delta E_{00}=5.4$, $p=0.0002$). For Day 28-PDP, the lowest color change was in ZLS-POL immersed in DIS ($\Delta E_{00}=1.3$, $p=0.0001$) and the highest color change was in FC-POL immersed in ENE ($\Delta E_{00}=4.2$, $p=0.0101$).

Bonferroni test results of BLE-material are shown in Table 4. For BAS-Day 1, the lowest color change was in non-BLE HC ($\Delta E_{00}=0.5$, $p<0.0001$) and the highest color change was in non-BLE ZLS-GLA ($\Delta E_{00}=2.8$, $p<0.0001$). For BAS-Day 14, the lowest color change was in HC without BLE ($\Delta E_{00}=0.7$, $p<0.0001$) and the highest color change was in ZLS-GLA with BLE ($\Delta E_{00}=2.3$, $p=0.0011$). For BAS-Day 28, the lowest color change was in BLE-treated ZLS-GLA ($\Delta E_{00}=1.2$, $p<0.0001$) and the highest color change was in BLE-treated FC-POL ($\Delta E_{00}=5.4$, $p<0.0001$). For Day 28-PDP, the lowest color change was in BLE-treated ZLS-POL ($\Delta E_{00}=1.5$, $p=0.0006$) and the highest color change was in non-BLE-treated HC ($\Delta E_{00}=4.6$, $p<0.0001$).

The results of the Bonferroni test of BLE-beverage are in Table 5. The values between specimens with and without BLE immersed in ENE for BAS-Day 14 ($p=0.0149$), in ENE or SAM for BAS-Day 28 ($p=0.0496$, $p=0074$, respectively), and in ENE or SAM for Day 14-Day 28 ($p=0.0039$, $p=0.0002$, respectively) were statistically different.

Bonferroni test results for material, beverage and BLE are in Table 6. For BAS-Day 1, the ranking of material color change was ZLS-GLA > FC-GLA > FC-POL > ZLS-POL > HC ($p=0.0003$). The ranking of material color change for BAS-Day 14 was ZLS-GLA > FC-POL > FC-GLA > FC-GLA > HC > ZLS-POL ($p=0.0011$). For BAS-Day 28, the ranking of material color change was FC-POL > FC-GLA = ZLS-GLA > ZLS-POL > HC ($p<0.0001$). The ranking of color change for Day 28-PDP material was HC > FC-POL > ZLS-POL > FC-GLA > ZLS-GLA ($p<0.0001$).

On BAS-Day 1, ZLS-GLA ($\Delta E_{00}=2.3$) had the highest color change and HC ($\Delta E_{00}=1.2$) had the lowest ($p=0.0003$). On BAS-Day 14, ZLS-GLA ($\Delta E_{00}=2.3$) had the highest color change and ZLS-POL ($\Delta E00=1.2$) had the lowest ($p=0.0011$). On BAS-Day 28, FC-POL ($\Delta E_{00}=4.2$) had the highest color change and HC ($\Delta E_{00}=2.0$) had the lowest ($p<0.0001$). On Day 28-PDP, HC ($\Delta E_{00}=3.3$) had the highest color change and ZLS-GLA ($\Delta E_{00}=1.8$) had the lowest ($p<0.0001$). On BAS-Day 28, beverage color change tended to be highest in ENE ($\Delta E_{00}=2.9$) and lowest in DIS ($\Delta E_{00}=2.3$) ($p<0.05$). On Day 28-PDP, the highest color change for the

Table 2 Results of 3-way ANOVA

	Source	SS	MS	FValue	ProbF	Cohend
BAS-Day 1	Material	38.205	9.551	6.932	**0.000**	0.785
	BLE	0.131	0.131	0.095	0.758	0.046
	Material-BLE	70.639	17.660	12.818	**0.000**	1.067
	Beverage	0.976	0.488	0.354	0.702	0.125
	Material-Beverage	21.374	2.672	1.939	0.057	0.587
	BLE-Beverage	0.964	0.482	0.350	0.705	0.125
	Material-BLE-Beverage	15.137	1.892	1.373	0.211	0.494
BAS-Day 14	Material	20.412	5.103	6.496	**0.000**	0.760
	BLE	10.654	10.654	13.564	**0.000**	0.549
	Material-BLE	22.412	5.603	7.133	**0.000**	0.796
	Beverage	0.690	0.345	0.439	0.645	0.140
	Material-Beverage	12.375	1.547	1.969	0.053	0.592
	BLE-Beverage	5.747	2.874	3.658	**0.028**	0.403
	Material-BLE-Beverage	27.825	3.478	4.428	**0.000**	0.887
BAS-Day 28	Material	148.497	37.124	17.151	**0.000**	1.235
	BLE	21.484	21.484	9.925	**0.002**	0.470
	Material-BLE	109.624	27.406	12.661	**0.000**	1.061
	Beverage	14.339	7.170	3.312	**0.039**	0.384
	Material-Beverage	87.951	10.994	5.079	**0.000**	0.950
	BLE-Beverage	19.202	9.601	4.436	**0.013**	0.444
	Material-BLE-Beverage	17.752	2.219	1.025	0.419	0.427
BAS-PDP	Material	153.277	38.319	17.979	**0.000**	1.264
	BLE	0.150	0.150	0.070	0.791	0.040
	Material-BLE	85.815	21.454	10.066	**0.000**	0.946
	Beverage	7.209	3.604	1.691	0.187	0.274
	Material-Beverage	39.091	4.886	2.293	**0.023**	0.638
	BLE-Beverage	14.206	7.103	3.333	**0.038**	0.385
	Material-BLE-Beverage	38.539	4.817	2.260	**0.025**	0.634
Day 1-Day 14	Material	74.935	18.734	11.954	**0.000**	1.031
	BLE	2.058	2.058	1.313	0.253	0.171
	Material-BLE	30.724	7.681	4.901	**0.001**	0.660
	Beverage	0.231	0.116	0.074	0.929	0.057
	Material-Beverage	10.206	1.276	0.814	0.591	0.380
	BLE-Beverage	1.016	0.508	0.324	0.724	0.120
	Material-BLE-Beverage	11.795	1.474	0.941	0.484	0.409
Day 14-Day 28	Material	187.317	46.829	19.849	**0.000**	1.328
	BLE	46.353	46.353	19.647	**0.000**	0.661
	Material-BLE	94.787	23.697	10.044	**0.000**	0.945
	Beverage	10.937	5.468	2.318	0.101	0.321
	Material-Beverage	44.933	5.617	2.381	**0.018**	0.651
	BLE-Beverage	44.410	22.205	9.412	**0.000**	0.647
	Material-BLE-Beverage	39.723	4.965	2.105	**0.038**	0.612
Day 28-PDP	Material	96.620	24.155	9.486	**0.000**	0.918
	BLE	0.184	0.184	0.072	0.789	0.040
	Material-BLE	51.598	12.899	5.066	**0.001**	0.671
	Beverage	20.991	10.496	4.122	**0.018**	0.428
	Material-Beverage	23.076	2.885	1.133	0.343	0.449
	BLE-Beverage	0.271	0.135	0.053	0.948	0.049
	Material-BLE-Beverage	10.073	1.259	0.494	0.859	0.296

Table 3 Bonferroni test results of beverage-material

		ENE (*n* = 70)	DIS (*n* = 70)	SAM (*n* = 70)	*P*[1]-value
BAS-Day 1	FC-GLA	1.8 (1.54)	2.4 (2.13)a	1.3 (0.61)	0.1943
	FC-POL	1.6 (1.21)	1.1 (0.44)[b]	1.9 (0.88)	0.0634
	ZLS-GLA	2.3 (1.31)	2.6 (1.40)[a]	2.2 (1.84)	0.7868
	ZLS-POL	1.1 (0.42)	0.9 (0.70)[b]	1.5 (2.24)	0.5283
	HC	1.3 (1.06)	0.7 (0.82)[b]	1.6 (1.22)	0.0887
p-value		0.1123	**0.0001**	0.5378	
BAS-Day 14	FC-GLA	1.9 (1.39)[a]	1.2 (1.16)	1.1 (0.48)[c]	0.1093
	FC-POL	1.1 (0.63)[b]	1.5 (1.54)	1.6 (1.12)[b]	0.5137
	ZLS-GLA	1.9 (0.80)[a]	1.9 (1.54)	2.3 (1.22)[a]	0.5789
	ZLS-POL	1.0 (0.64)[b]	1.3 (0.78)	0.9 (0.46)[c]	0.1654
	HC	1.4 (1.06)[b]	1.0 (0.79)	1.5 (0.98)[b]	0.2579
p-value		**0.0316**	0.3935	**0.0015**	
BAS-Day 28	FC-GLA	2.6 (1.35)[b, A]	1.5 (1.01)[c, B]	2.6 (1.23)[A]	**0.0271**
	FC-POL	5.4 (4.27)[A, a]	4.8 (1.20)[a, A]	2.4 (1.95)[B]	**0.0177**
	ZLS-GLA	1.7 (1.07)[c]	2.2 (1.55)[b]	2.7 (1.09)	0.1299
	ZLS-POL	2.1 (1.12)[b]	2.0 (1.35)[b]	2.1 (2.06)	0.9810
	HC	2.7 (1.08)[b, A]	1.3 (0.81)[c, B]	1.9 (1.07)[B]	**0.0028**
p-value		**0.0002**	**0.0001**	0.6659	
BAS-PDP	FC-GLA	1.9 (0.97)[b]	1.8 (1.50)[c]	2.0 (0.33)[c]	0.8502
	FC-POL	4.4 (5.03)[a]	3.5 (0.41)[a]	2.7 (1.35)[b]	0.3205
	ZLS-GLA	2.2 (0.65)[b]	2.9 (1.77)[b]	2.7 (0.98)[b]	0.2888
	ZLS-POL	1.5 (0.72)[C, b]	1.2 (0.74)[c, B]	2.0 (0.92)[c, A]	**0.0716**
	HC	4.5 (1.24)[a, A]	2.9 (0.95)[b, C]	3.7 (0.82)[a, B]	**0.0010**
p-value		**0.0013**	**0.0001**	**< 0.0001**	
Day 1-Day 14	FC-GLA	1.5 (2.10)[b]	1.5 (1.92)[b]	0.5 (0.46)[c]	0.2184
	FC-POL	1.1 (0.39)[b]	1.0 (1.30)[b]	1.2 (0.44)[b]	0.9199
	ZLS-GLA	2.2 (1.34)[a]	2.1 (2.15)[a]	2.4 (1.77)[a]	0.9292
	ZLS-POL	0.9 (0.48)[c]	0.9 (0.53)[b]	1.3 (2.15)[b]	0.7320
	HC	0.4 (0.24)[c]	0.4 (0.16)[c]	0.3 (0.28)[c]	0.9302
p-value		**0.0017**	**0.0287**	**0.0008**	
Day 14-Day 28	FC-GLA	2.8 (1.85)[b, A]	1.6 (0.42)[c, B]	1.9 (0.89)[b, B]	**0.0266**
	FC-POL	4.9 (4.63)[a]	4.1 (1.84)[a]	2.9 (2.33)[a]	0.2487
	ZLS-GLA	2.2 (1.26)[c]	2.2 (2.16)[b]	3.2 (1.19)[a]	0.1272
	ZLS-POL	2.1 (1.20)[c]	2.4 (1.51)[b]	2.0 (1.75)[b]	0.7405
	HC	1.4 (0.38)[d, A]	0.8 (0.75)[c, B]	0.9 (0.44)[c, B]	**0.0192**
p-value		**0.0027**	**0.0001**	**0.0006**	
Day 28-PDP	FC-GLA	1.7 (0.84)[b, B]	1.5 (0.99)[c, B]	2.6 (0.66)[A]	**0.0065**
	FC-POL	4.2 (4.53)[a]	2.4 (1.01)[b]	3.0 (1.61)	0.2431
	ZLS-GLA	1.8 (0.81)[b]	1.6 (0.60)[c]	2.0 (1.10)	0.4761
	ZLS-POL	1.9 (1.53)[b]	1.3 (1.25)[c]	2.5 (1.94)	0.1670
	HC	3.6 (1.29)[a]	3.1 (1.17)[a]	3.3 (0.95)	0.5254
p-value		**0.0101**	**0.0001**	0.1085	

[1] ANOVA F-test p-value: Same superscript lowercase letters represent no significant difference in columns and same superscript capital letters indicate no significant difference in rows

Table 4 Bonferroni test results of BLE-material

		No (*n* = 105)	Yes (*n* = 105)	*p*-value
BAS-Day 1	FC-GLA	1.2 (1.19)[b]	2.4 (1.73)[a]	**0.0122**
	FC-POL	2.2 (0.66)[a]	0.8 (0.62)[c]	**< 0.0001**
	ZLS-GLA	2.8 (1.99)[a]	1.8 (0.35)[b]	**0.0246**
	ZLS-POL	1.4 (1.84)[b]	0.9 (0.54)[c]	0.2412
	HC	0.5 (0.51)[c]	2.0 (1.03)[a]	**< 0.0001**
p-value		**< 0.0001**	**< 0.0001**	
BAS-Day 14	FC-GLA	0.9 (0.40)[b]	1.9 (1.38)[a]	**0.0040**
	FC-POL	1.5 (0.35)[a]	1.4 (1.61)[b]	0.7361
	ZLS-GLA	1.8 (1.25)[a]	2.3 (1.14)[a]	0.1634
	ZLS-POL	1.3 (0.77)[a]	0.9 (0.44)[b]	**0.0306**
	HC	0.7 (0.44)[b]	2.0 (0.88)[a]	**< 0.0001**
p-value		**< 0.0001**	**0.0011**	
BAS-Day 28	FC-GLA	1.8 (0.75)[b]	2.7 (1.56)[b]	**0.0239**
	FC-POL	3.0 (1.35)[a]	5.4 (3.74)[a]	**0.0094**
	ZLS-GLA	3.2 (0.77)[a]	1.2 (0.83)[c]	**< 0.0001**
	ZLS-POL	1.5 (1.29)[b]	2.7 (1.53)[b]	**0.0091**
	HC	1.6 (0.89)[b]	2.3 (1.23)[b]	**0.0273**
p-value		**< 0.0001**	**< 0.0001**	
BAS-PDP	FC-GLA	1.8 (0.77)[d]	2.0 (1.24)[c]	0.4350
	FC-POL	2.5 (0.96)[c]	4.6 (3.96)[a]	0.0263
	ZLS-GLA	3.4 (1.18)[b]	1.7 (0.55)[c]	< 0.0001
	ZLS-POL	1.5 (0.99)[d]	1.7 (0.66)[c]	0.5469
	HC	4.2 (1.15)[a]	3.2 (0.98)[b]	0.0021
p-value		**< 0.0001**	**< 0.0001**	
Day 1-Day 14	FC-GLA	0.7 (1.30)[c]	1.7 (1.90)[a]	0.0503
	FC-POL	1.1 (0.43)[b]	1.1 (1.07)[b]	0.9027
	ZLS-GLA	2.9 (2.17)[a]	1.6 (0.83)[a]	0.0159
	ZLS-POL	1.4 (1.75)[b]	0.7 (0.29)[b]	0.0875
	HC	0.4 (0.24)[c]	0.3 (0.22)[c]	0.2482
p-value		**< 0.0001**	**< 0.0001**	
Day 14-Day 28	FC-GLA	1.7 (0.64)[b]	2.5 (1.65)[b]	0.0519
	FC-POL	2.2 (0.95)[a]	5.7 (3.69)[a]	**0.0001**
	ZLS-GLA	2.4 (1.82)[a]	2.7 (1.48)[b]	0.5397
	ZLS-POL	2.0 (1.66)[a]	2.3 (1.29)[b]	0.5344
	HC	1.1 (0.65)[c]	0.9 (0.52)[c]	0.2117
p-value		**0.0196**	**< 0.0001**	
Day 28-PDP	FC-GLA	1.8 (0.84)[b]	2.1 (1.02)[b]	0.4112
	FC-POL	2.4 (1.21)[b]	4.0 (3.74)[a]	0.0676
	ZLS-GLA	1.9 (1.00)[b]	1.7 (0.71)[c]	0.5324
	ZLS-POL	2.2 (1.67)[b]	1.6 (1.57)[c]	0.2270
	HC	4.0 (0.90)[a]	2.7 (0.93)[b]	**< 0.0001**
p-value		**< 0.0001**	**0.0006**	

beverage was in ENE ($\Delta E_{00} = 2.7$) and the lowest in DIS ($\Delta E_{00} = 2.0$) ($p = 0.0355$).

Discussion

In this study, two hypotheses were rejected, because material/polishing method, BLE, beverages and PDP led to discoloration of the tested materials. The CIEDE2000 color difference formula (ΔE_{00}) is reported to be superior to the previously used CIELAB formula (ΔE_{ab}) in terms of perceptibility and acceptability of color difference. This

Table 5 Bonferroni test results of BLE-beverage

		No (*n* = 105)	Yes (*n* = 105)	*p*-value
BAS-Day 1	ENE	1.6 (1.24)	1.6 (1.18)	0.9579
	DIS	1.5 (1.54)	1.6 (1.37)	0.8333
	SAM	1.8 (1.91)	1.6 (0.87)	0.5032
p-value		0.7041	0.9380	
BAS-Day 14	ENE	1.2 (0.57)	1.8 (1.24)	**0.0149**
	DIS	1.4 (1.18)	1.4 (1.27)	0.9934
	SAM	1.1 (0.52)	1.9 (1.22)	0.0009
p-value		0.3879	0.1915	
BAS-Day 28	ENE	2.3 (0.96)	3.5 (3.31)	**0.0496**
	DIS	2.4 (1.53)	2.2 (1.92)	0.6186
	SAM	1.9 (1.20)	2.8 (1.67)	**0.0074**
p-value		0.1299	0.1033	
BAS-PDP	ENE	2.6 (1.56)	3.2 (3.43)	0.2995
	DIS	2.7 (1.55)	2.2 (1.23)	0.1061
	SAM	2.7 (1.18)	2.5 (1.05)	0.3030
p-value		0.8541	0.1193	
Day 1-Day 14	ENE	1.2 (1.09)	1.2 (1.45)	0.9864
	DIS	1.3 (1.80)	1.1 (1.18)	0.4764
	SAM	1.3 (1.88)	1.0 (0.77)	0.3426
p-value		0.9628	0.6816	
Day 14-Day 28	ENE	1.8 (1.05)	3.6 (3.32)	**0.0039**
	DIS	2.4 (1.69)	2.0 (1.92)	0.4277
	SAM	1.5 (0.86)	2.9 (1.96)	**0.0002**
p-value		0.0101	0.0427	
Day 28-PDP	ENE	2.6 (1.60)	2.7 (3.09)	0.9696
	DIS	2.1 (1.33)	1.9 (1.06)	0.5992
	SAM	2.7 (1.17)	2.7 (1.56)	0.8857
p-value		0.1131	0.2363	

formula, developed by the CIE in 2013, is considered the standard for color difference detection. The ΔE_{ab} formula basically measures the distance between two points in color space, whereas the ΔE_{00} formula includes the luminance effect by adding S_L [23]. Therefore, the ΔE_{00} color difference formula was chosen for this study. In previous studies testing CAD-CAM FC [22], ZLS [23] and HC [24], 0.8/1.8 was found to be appropriate for PT/AT values; therefore, 0.8/1.8 was chosen for PT/AT in this study.

Spectrophotometers, spectroradiometers, colorimeters and digital cameras are currently the most recommended instruments for color measurement in dentistry. Spectroradiometers designed for the measurement of radiometric values are the most recommended instruments for determination of the tooth color or translucency of the ceramic core structure [25]. In this study, we aimed to investigate color change on the surfaces of dental materials due to external factors. Spectroradiometers are extremely sensitive instruments, where even the slightest error in the position of the measuring device is difficult to tolerate and should be handled with extreme caution. In this study, since a total of 5 measurements were taken from 210 specimens, it was necessary to select a device more suitable for the working conditions. For these reasons, the Vita Easyshade V spectrophotometer device was used in this study [26].

Moreover, this instrument was used in previous studies for teeth [27], polymethyl methacrylates [28], resin composites [29] and ceramics [9]. Dozic et al. [30] stated that Vita Easyshade can make reliable measurements compared with some colorimeters and digital cameras and explained that these three different types of devices can be tested in in vitro studies. Igiel et al. [31] stated that given their accuracy (from 66.8 to 92.6%) and precision (from 87.4 to 99.0%), it is an excellent example among color determination methods. In this study, a custom-made color booth was prepared to ensure standardization and to prevent ambient light from causing errors [20].

According to the results, the color change exceeded the AT after 28 days in all specimens, except for FC-GLA and HC immersed in DIS and ZLS-GLA specimens immersed in ENE. Between day 1 and day 14, AT was exceeded in all other specimens, except for ZLS-GLA immersed in DIS, ENE or SAM. From day 14 to day 28, AT was exceeded only in FC-GLA immersed in DIS and not in HC immersed in DIS, ENE or SAM. When the color change values obtained from BAS to day 1, BAS to day 14 or BAS to day 28 were examined, no specimens, regardless of the beverage in which they were immersed, had a color change lower than PT.

In this study, a new HP formula (25% HPS) was used for in-office BLE. In this study, BLE was found to be influenced in color change of restorative materials, which was consistent with previous studies [8, 32, 33]. Conventional in-office BLE gels mostly contain 30–35% HP. It has been reported by the manufacturer that 25% HPS has a different content than conventional in-office BLE gels and therefore is more effective [34]. It was necessary to investigate this claim. In previous studies [8, 32] the 6% formulation of HPS used for at-home BLE was tested and the magnitude of the effect was found increased with time. In this study, 25% HPS produced a similarly noticeable effect on the materials tested. According to the results, at the end of 28 days, the color change did not exceed AT in FC-GLA, ZLS-POL and HC specimens without BLE, but exceeded it in specimens with BLE ($p=0.0239$, $p=0.0091$, $p=0.0273$, respectively). These results were possibly due to the amount of content and concentration. In contrast to conventional BLE gels, HPS contains CP and vinyl pyrrolidone peroxide in combination, as well as heat-reversible poloxamer to adjust the viscosity. When the gel comes into contact with the tooth surface, an exothermic reaction cycle occurs, resulting in an increase in the magnitude of the effect.

When the BLE agent contacts the surface of a ceramic material for a long time, it may cause surface

Table 6 Bonferroni test results for material, beverage and BLE

	FC-GLA ($n=42$)	FC-POL ($n=42$)	ZLS-GLA ($n=42$)	ZLS-POL ($n=42$)	HC ($n=42$)	*p*-Value
BAS-Day 1	1.8 (1.59)^B	1.5 (0.94)^B	2.3 (1.51)^A	1.2 (1.36)^C	1.2 (1.09)^C	**0.0003**
BAS-Day 14	1.4 (1.12)^B	1.4 (1.15)^B	2.0 (1.21)^A	1.1 (0.66)^C	1.3 (0.96)^B	**0.0011**
BAS-Day 28	2.2 (1.29)^B	4.2 (3.03)^A	2.2 (1.29)^B	2.1 (1.52)^B	2.0 (1.13)^B	**<0.0001**
BAS-PDP	1.9 (1.03)^C	3.5 (3.03)^A	2.6 (1.23)^B	1.6 (0.83)^C	3.7 (1.19)^A	**<0.0001**
Day 1-Day 14	1.2 (1.69)^B	1.1 (0.81)^B	2.2 (1.74)^A	1.0 (1.29)^B	0.4 (0.23)^C	**<0.0001**
Day 14-Day 28	2.1 (1.29)^B	4.0 (3.21)^A	2.5 (1.64)^B	2.2 (1.48)^B	1.0 (0.59)^C	**<0.0001**
Day 28-PDP	1.9 (0.93)^B	3.2 (2.87)^A	1.8 (0.86)^B	1.9 (1.63)^B	3.3 (1.14)^A	**<0.0001**
			ENE ($n=70$)	**DIS** ($n=70$)	**SAM** ($n=70$)	**p-value**
BAS-Day 1			1.6 (1.20)	1.5 (1.45)	1.7 (1.48)	0.7742
BAS-Day 14			1.5 (1.00)	1.4 (1.21)	1.5 (1.01)	0.7438
BAS-Day 28			2.9 (2.49)	2.3 (1.72)	2.3 (1.52)	0.1569
BAS-PDP			2.9 (2.66)	2.5 (1.42)	2.6 (1.12)	0.3539
Day 1-Day 14			1.2 (1.27)	1.2 (1.51)	1.1 (1.44)	0.9437
Day 14-Day 28			2.7 (2.60)	2.2 (1.81)	2.2 (1.66)	0.2794
Day 28-PDP			2.7 (2.44)^A	2.0 (1.20)^B	2.7 (1.37)^A	**0.0355**
				No ($n=105$)	**Yes** ($n=105$)	**p-value**
BAS-Day 1				1.6 (1.57)	1.6 (1.15)	0.7934
BAS-Day 14				1.2 (0.81)	1.7 (1.25)	**0.0022**
BAS-Day 28				2.2 (1.27)	2.9 (2.44)	**0.0181**
BAS-PDP				2.7 (1.43)	2.6 (2.21)	0.8354
Day 1-Day 14				1.3 (1.62)	1.1 (1.16)	0.3087
Day 14-Day 28				1.9 (1.30)	2.8 (2.54)	**0.0009**
Day 28-PDP				2.5 (1.40)	2.4 (2.10)	0.8103

deterioration as in resin composites. Free radicals such as H^+ and H_3O^+ produced by alkali ions infiltrate into the material matrix and cause dissolution of ceramic glass networks, disintegration of SiO_2 and K_2O_2 components, abrasion of the surface, destruction of chromogens and formation of a less light-reflecting surface. The quality of surface polishability reduces the magnitude of exposure to external factors [35]. Alshali et al. [36] reported that the polishability quality may change depending on the material structure. In this study, when the results of BLE treated ceramic specimens after 28 days were analyzed, it was found that mechanically polished FC was more influenced than glazed FC, mechanically polished ZLS was more influenced than glazed FC and mechanically polished ceramics were more influenced than hybrid ceramic ($p<0.0001$).

Previous studies [35, 37] had reported that the application time is significant in the effect of BLE on ceramics. Similar to this study, the number of studies in which glazed and mechanically polished ceramics were examined together is insufficient, and studies [14, 33] found that glazed surfaces were less affected than mechanically polished surfaces in parallel with this study. The researchers reported that the magnitude of the effect of BLE is related to the application time.

FCs have microstructurally a single-phase and multiporous structure. In ZLSs, lithium disilicate crystals have a large, rod-like appearance and cerium, the equalizing material of zirconium oxide and tetragonal zirconium, is properly dispersed throughout the structure. In this study, with BLE or ENE, higher resistance to color change after 28 days was obtained for glazed FCs and ZLSs than for mechanically polished ones. In a study by Ramos et al. [38] using energy dispersive spectroscopy (EDS), it was found that the needle-like rods on the surface of ZLS were so covered that they were invisible. This may be an indicates that the glaze layer is able to protect the material well against external factors.

Furthermore, Ramos et al. [38] stated that according to the results of the study, the water permeability of HC and the resulting degradation of its structure should be investigated, and it was surprising that the calculated density of HC was higher than FC and ZLS. As can be seen, HC is a suitable material for testability and therefore hybrid ceramics were used for comparison with ceramics. In this study, the components such as hydrophobic urethane dimethacrylate (UDMA) and hydrophilic triethylene glycol dimethacrylate (TEGDMA) may also be effective in the color change on the surface of HC. In the study by Asthiani et al. [39], HC was more affected by beverages than ZLS and reported that this was due to TEGDMA absorbing staining pigments into the material.

The focus of this study was to investigate three materials with different structures and the selection of materials was structurally based on the fact that all three materials were ceramic based. The first material was a feldspathic ceramic, which has been used in the majority of studies. The other was zirconia-reinforced lithium disilicate ceramic, which is a newly developed product. Since it is a newly developed product, hybrid ceramic, which is a polymer infiltrated ceramic, was selected as the third material [38]. The selection of material during the design of the study was in accordance with the study by Ramos et al. [38]. In HC, it is claimed that the cracks in the polymer network are stopped by the ceramic phase and therefore the structural reliability is high, but it was necessary to determine to what extent the superiority of this ceramic over color-changing agents was different [38].

Resin-nanoceramics are alternative to HCs. Lava Ultimate (3 M ESPE), one of these, contains 80% nanofiller by weight and CeraSmart (GC Dental), another product, 71%. These products are probably produced at high pressure and temperature [40]. Unlike resin composites, HCs contain two interconnected networks, polymer and ceramic. In a previous study [41], a crystalline structure with leucite and secondary zirconium surrounded by polymer was identified in HCs. HCs are more similar to ceramics than resin-nanoceramic materials in terms of causing wear on opposing teeth and elastic modulus value. Moreover, Lava Ultimate (3 M ESPE), a resin-nanoceramic product, is not recommended by the manufacturer for full crowns because it produces micro-segregation at the interface between the crown and tooth under occlusal load [40]. In this study, we wanted to evaluate the more commonly recommended materials for full crowns; therefore, Lava Ultimate was eliminated. For comparison with ceramics, HCs, which are closer in structural properties to ceramics, were preferred compared to resin-nanoceramics.

Dental materials can be discolored over time by saliva or acidic beverages [42]. In this study, RedBull energy beverage with a pH of 3.18 was used [11]. Silva et al. [11] reported that the surface degrading effect of RedBull varied with consumption frequency and time. Elhamid and Mosallam [43] found that even when carbon dioxide evaporated from energy beverages, the pH level remained low. Dos Santos et al. [44] reported that citric acid in carbonated beverages is the main factor for material surface degradation. Acidic beverages for dental ceramics cause selective extraction of alkali metal ions with low stabilisation in the glass matrix. Insufficient polymerisation of the material, water absorption and the pigment type of the beverage for resin-containing ceramics are important factors [45]. ENE and SAM used in this study, contain citric acid and staining pigments. The staining pigments contained in these beverages possibly caused the discoloration and over time the acid caused the surface of the material to deteriorate, facilitating the retention of the pigment.

In this study, FC-POL immersed in ENE had the highest color change after 28 days ($\Delta E_{00}=5.4$, $p=0.0002$) and HC immersed in DIS had the lowest color change ($\Delta E_{00}=1.3$, $p=0.0001$). According to the BLE-beverage interaction, at the end of 28 days, the highest color change was found in the specimens with BLE and immersed in ENE ($\Delta E_{00}=3.5$, $p=0.0496$), and the lowest in the specimens without BLE and immersed in SAM ($\Delta E_{00}=1.9$, $p=0.0074$). When the literature was reviewed, no study on the effect of energy beverages on HC was found, but a few studies [12, 46] on the effect of energy beverages on ZLS were found and in these studies, it was reported that low pH and dietary habits affected on the effect of energy beverages on discoloration. Since energy beverage consumption increased especially in young people after the Covid-19 pandemic, this type of study was needed [12].

There are many studies investigating the effect of beverages on the color of restorative materials. These studies mostly include beverages such as tea, coffee, cola, and wine [19, 46]. There is no study in the literature on the effect of immune-boosting beverage with black elderberry, whose consumption has increased since the Covid-19 pandemic due to its antiviral properties, on the color of ceramic [47]. Tokuc and Sukur [48] evaluated resin composites for white spot lesions in their study on children's teeth. Consistent with this study, Sambucus Nigra caused clinically unacceptable color change. In this study, after 28 days, SAM tended to produce a color change similar to DIS. The fact that the specimens had been subjected to BLE increased the magnitude of color change due to SAM.

PDP is a polishing procedure that the majority of clinicians perform after prosthetic treatment to remove discoloration and plaque deposits [13]. Nowadays, a new generation of PDP pastes with lower dentin abrasiveness has been developed and their effects on dental materials should be investigated. This study is in agreement with the study of Elhamid and Mosallam [43] who investigated the effect of PDP on resin composites. Depending on the type of paste, the effect of PDP on the surface may differ [49]. In this study, a paste containing fine silica particles with a RDA of 7 was used. According to the findings of this study, PDP is effective for restoring the color of materials discolored by beverages. This restoring effect was most successful in ZLS-GLA and HC for ENE, FC-GLA, ZLS-GLA and HC for DIS, and FC-POL and HC for SAM. Regardless of the beverage, when BLE and non-BLE specimens were compared, color recovery was more successful in non-BLE specimens; HC and ZLS-GLA were superior to other materials in this respect. Regardless of the material, when evaluated in terms of BLE-beverage, color recovery was better in all specimens without BLE and immersed in DIS, ENE or SAM compared to those with BLE.

Ceramic stains contain pigments composed of raw metal oxides. The color of ceramics after firing may vary depending on the type of ceramic or stain. In a previous study [50], yellow stain applied to body porcelain increased the gloss of the porcelain, whereas blue, purple and red stains decreased it. In another study [51], it was reported that yellow and orange stains exhibited low color stability during firing. Color differences may result due to the addition of metal oxides under different oxidation conditions [52]. The magnitude of the porosities in the ceramic structure, number of firings and temperature can also cause changes in the color effect of stain pigments [53]. In this study, in order to standardize the glazing conditions, only the glazing powder-liquid set suitable for the glazing process was used, without the use of external stains.

A limitation of this study was that intraoral conditions cannot be fully simulated. Exposing both sides of the specimens to beverages does not fully represent clinical scenarios where only one side is mostly exposed to colorants. This study adds to the literature in many ways, but future in vivo and in vitro studies are needed to investigate the effects of immune-boosting beverages, energy beverages, bleaching and new PDP paste on the surface properties of newly developed CAD-CAM materials.

Conclusions

The results within the limitations of this study are as follows:

1. After 28 days, the highest color change was in FC-POL immersed to ENE and the lowest in HC immersed to DIS. Color recovery by PDP was most effective in HC specimens immersed ENE, DIS or SAM.
2. The BLE treatment of the materials resulted in a higher magnitude of color change due to beverages. In both BLE and non-BLE HC specimens, PDP provided effective correction of color. At the end of 28 days, the highest color change was found in specimens immersed in ENE and BLE, and the lowest in specimens immersed in SAM and no BLE. Color recovery was lower in BLE treated specimens compared to non-BLE treated specimens, regardless of the beverage in which they were immersed.
3. In terms of material, FC-POL had the highest color change and HC the lowest, while in terms of beverage, ENE had the highest color change and SAM and DIS the lowest.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12903-024-04895-2.

Supplementary Material 1
Supplementary Material 2
Supplementary Material 3
Supplementary Material 4
Supplementary Material 5
Supplementary Material 6
Supplementary Material 7
Supplementary Material 8
Supplementary Material 9
Supplementary Material 10
Supplementary Material 11
Supplementary Material 12
Supplementary Material 13
Supplementary Material 14
Supplementary Material 15
Supplementary Material 16
Supplementary Material 17
Supplementary Material 18
Supplementary Material 19
Supplementary Material 20
Supplementary Material 21
Supplementary Material 22
Supplementary Material 23
Supplementary Material 24
Supplementary Material 25

Acknowledgements
I would like to thank, Pharmacist Gülşah Akbülbül Yılmaz for her efforts.

Author contributions
K.Y. Creation of the methodology, preparation of specimens, performing the tests, writing the manuscript. E.Ö. Writing the tables and figures, visualisation, writing the manuscript. F. G. Project administration, validation, writing the manuscript.

Funding
The authors do not have any financial interest in the companies whose materials are included in this article.

Data availability
The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Ethical approval is not applicable as this is an in vitro study in which humans and animals, including materials/data, are not used for experimental purposes.

Consent for publication
As this article is an in vitro study not involving human use, consent for publication is not required.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Prosthodontics, Faculty of Dentistry, Bilimdent Oral and Dental Health Center (ADSUAM), Antalya Bilim University, Tahılpazarı Mahallesi, Kazım Özalp Street, No: 84/D, Floor 9, Muratpaşa, Antalya 07040, Turkey
[2]Özdemir Dental Center, Antalya, Turkey
[3]Department of Prosthodontics, Faculty of Dentistry, Ankara University, Ankara, Turkey

Received: 20 June 2024 / Accepted: 11 September 2024
Published online: 17 September 2024

References

1. Paolone G, Mandurino M, De Palma F, Mazzitelli C, Scotti N, Breschi L, et al. Color stability of polymer-based composite CAD/CAM blocks: a systematic review. Polym (Basel). 2023;15(2):464.
2. Zarone F, Ruggiero G, Leone R, Breschi L, Leuci S, Sorrentino R. Zirconia-reinforced lithium silicate (ZLS) mechanical and biological properties: a literature review. J Dent. 2021;109:103661.
3. Acar O, Yilmaz B, Altintas SH, Chandrasekaran I, Johnston WM. Color stainability of CAD/CAM and nanocomposite resin materials. J Prosthet Dent. 2016;115(1):71–5.
4. da Silva TM, Salvia ACRD, de Carvalho RF, Pagani C, da Rocha DM, da Silva EG. Polishing for glass ceramics: which protocol? J Prosthodont Res. 2014;58(3):160–70.
5. Alencar-Silva FJ, Barreto JO, Negreiros WA, Silva PGB, Pinto-Fiamengui LMS, Regis RR. Effect of beverage solutions and toothbrushing on the surface roughness, microhardness, and color stainability of a vitreous CAD-CAM lithium disilicate ceramic. J Prosthet Dent. 2019;121(4):e7111–6.
6. Tinastepe N, Malkondu O, Iscan I, Kazazoglu E. Effect of home and over the contour bleaching on stainability of CAD/CAM esthetic restorative materials. J Esthet Restor Dent. 2021;33(2):303–13.
7. Yılmaz MN, Gul P. Susceptibility to discoloration of dental restorative materials containing dimethacrylate resin after bleaching. Odontology. 2023;111(2):376–86.
8. Carneiro TS, Favoreto MW, Mena-Serrano A, Wendlinger M, Forville H, Reis A, et al. In vitro evaluation of the effect of different bleaching varnishes: hydrogen peroxide penetration into the pulp chamber and color change. J Esthet Restor Dent. 2024;36(2):402–9.
9. Sugiyama T, Kameyama A, Enokuchi T, Haruyama A, Chiba A, Sugiyama S, et al. Effect of professional dental prophylaxis on the surface gloss and roughness of CAD/CAM restorative materials. J Clin Exp Dent. 2017;9(6):e772–8.
10. Islam MS, Aal-Fatlah AA, Alkhan NS, Aryal Ac S, Sadr A, Rehman MM. The effect of different finishing polishing protocols on stain absorption and color stability of resin composite restorations. Am J Dent. 2022;35(2):141–5.
11. Silva JGVC, Martins JPG, de Sousa EBG, Fernandes NLS, Meira IA, Sampaio FC, et al. Influence of energy drinks on enamel erosion: in vitro study using different assessment techniques. J Clin Exp Dent. 2021;13(11):e1076–82.
12. Alaqeel S. Effect of grit-blasting on the color stability of zirconia ceramics following exposure to beverages. Cureus. 2020;12(3):e7170.
13. Çakmak G, Subaşı MG, Sert M, Yilmaz B. Effect of surface treatments on wear and surface properties of different CAD-CAM materials and their enamel antagonists. J Prosthet Dent. 2023;129(3):495–506.
14. Ozdogan A, Kaya N. Effectiveness and safety of bleaching agents on lithium disilicate glass ceramics. J Dent Res Dent Clin Dent Prospects. 2022;16(4):251–7.
15. Sen N, Sermet IB, Cinar S. Effect of coloring and sintering on the translucency and biaxial strength of monolithic zirconia. J Prosthet Dent. 2018;119(2):e3081–7.
16. Weeranoppanant P, Palanuwech M. Effects of ceramic thickness and titanium anodization on esthetic outcomes of lithium disilicate ceramic over titanium alloys. Eur J Prosthodont Restor Dent. 2023;31(1):40–9.
17. Cavex Bite&White In-Office. Instructions for use. 2024. https://www.cavex.nl/producten/whitening-and-oral-care-en/whitening-en/cavex-bitewhite-in-office-systeem/?lang=en. Accessed 24 July 2024.
18. Ertaş E, Güler AU, Yücel AC, Köprülü H, Güler E. Color stability of resin composites after immersion in different drinks. Dent Mater J. 2006;25(2):371–6.
19. Miyashita-Kobayashi A, Haruyama A, Nakamura K, Wu CY, Kuroiwa A, Yoshinari N, et al. Changes in gloss alteration, surface roughness, and color of direct dental restorative materials after professional dental prophylaxis. J Funct Biomater. 2023;15(1):8.
20. Shokry TE, Shen C, Elhosary MM, Elkhodary AM. Effect of core and veneer thicknesses on the color parameters of two all-ceramic systems. J Prosthet Dent. 2006;95(2):124–9.
21. Luo XP, Zhang L. Effect of veneering techniques on color and translucency of Y-TZP. J Prosthodont. 2010;19(6):465–70.
22. Sampaio CS, Belfus J, Avila A, Cordero C, Freitte M, Ferrari V, et al. Effect of different fabrication steps on color and translucency of a CAD-CAM feldspathic ceramic. J Esthet Restor Dent. 2021;33(7):1038–44.
23. Tejada-Casado M, Ghinea R, Perez MM, Lübbe H, Pop-Ciutrila IS, Ruiz-López J, et al. Reflectance and color prediction of dental material monolithic samples with varying thickness. Dent Mater. 2022;38(4):622–31.
24. Wu Z, Tian J, Wei D, Di P, Lin Y. Quantitative analysis of color accuracy and bias in 4 dental CAD-CAM monolithic restorative materials with different thicknesses: an in vitro study. J Prosthet Dent. 2022;128(1):e921–7.
25. Brewer JD, Wee A, Seghi R. Advances in color matching. Dent Clin North Am., Wee JD, Seghi A. R. Advances in color matching. Dent Clin North Am. 2004;48(2):v, 341–58.
26. Joiner A, Luo W. Tooth colour and whiteness: a review. J Dent. 2017;67S:S3–10.
27. Forabosco E, Consolo U, Mazzitelli C, Kaleci S, Generali L, Checchi V. Effect of bleaching on the color match of single-shade resin composites. J Oral Sci. 2023;65(4):232–6.
28. de Castro EF, Nima G, Rueggeberg FA, Araújo-Neto VG, Faraoni JJ, Palma-Dibb RG, et al. Effect of build orientation in gloss, roughness and color of 3D-printed resins for provisional indirect restorations. Dent Mater. 2023;39(7):e1–11.
29. Assaf C, Abou Samra P, Nahas P. Discoloration of resin composites induced by coffee and tomato sauce and subjected to surface polishing: an in vitro study. Med Sci Monit Basic Res. 2020;26:e923279.
30. Dozić A, Kleverlaan CJ, El-Zohairy A, Feilzer AJ, Khashayar G. Performance of five commercially available tooth color-measuring devices. J Prosthodont. 2007;16(2):93–100.
31. Igiel C, Lehmann KM, Ghinea R, Weyhrauch M, Hangx Y, Scheller H, et al. Reliability of visual and instrumental color matching. J Esthet Restor Dent. 2017;29(5):303–8.
32. Yildirim E, Vural UK, Cakir FY, Gurgan S. Effects of different over – the – counter whitening products on the microhardness, surface roughness, color and shear bond strength of enamel. Acta Stomatol Croat. 2022;56(2):120–31.
33. Murat S, Batak B, Yilmaz D, Öztürk C. Effects of 16% carbamide peroxide on optical properties of thermally aged monolithic CAD-CAM glass ceramics with different surface treatments. Oper Dent. 2023;48(2):176–85.
34. What makes. 'hydrogen peroxide superior' superior? 2024. https://www.cavex.nl/hydrogen-peroxide-superior/?lang=en. Accessed 20 June 2024.
35. Rodrigues CRT, Turssi CP, Amaral FLB, Basting RT, França FMG. Changes to glazed dental ceramic shade, roughness, and microhardness after bleaching and simulated brushing. J Prosthodont. 2019;28(1):e59–67.
36. Alshali RZ, Alqahtani MA. The effect of home and in-office bleaching on microhardness and color of different CAD/CAM ceramic materials. Mater (Basel). 2022;15(17):5948.
37. Alkurt M, Duymus ZY, Yildiz S. How home bleaching agents affect the color and translucency of CAD/CAM monolithic zirconia materials. Dent Mater J. 2022;41(4):511–9.
38. Ramos N, de Campos C, Paz TMB, de Machado IS, Bottino JPB, Cesar MA. Microstructure characterization and SCG of newly engineered dental ceramics. Dent Mater. 2016;32(7):870–8.
39. Ashtiani ER, Beyabanaki E, Razmgah M, Salazar A, Revilla-León M, Zandinejad A. Color stability of resin hybrid ceramic materials in comparison to zirconia-reinforced lithium silicate ceramic. Front Dent. 2023;20:37. https://doi.org/10.18502/fid.v20i37.13742.
40. Lawson NC, Bansal R, Burgess JO. Wear, strength, modulus and hardness of CAD/CAM restorative materials. Dent Mater. 2016;32(11):e275–83.
41. Della Bona A, Corazza PH, Zhang Y. Characterization of a polymer-infiltrated ceramic-network material. Dent Mater. 2014;30(5):564–9.
42. Sulaiman TA, Abdulmajeed AA, Shahramian K, Hupa L, Donovan TE, Vallittu P, et al. Impact of gastric acidic challenge on surface topography and optical properties of monolithic zirconia. Dent Mater. 2015;31(12):1445–52.
43. Elhamid MA, Mosallam R. Effect of bleaching versus repolishing on colour and surface topography of stained resin composite. Aust Dent J. 2010;55(4):390–8.

44. Dos Santos DM, da Silva EVF, Watanabe D, Bitencourt SB, Guiotti AM, Goiato MC. Effect of different acidic solutions on the optical behavior of lithium disilicate ceramics. J Prosthet Dent. 2017;118(3):430–6.
45. Alharbi A, Ardu S, Bortolotto T, Krejci I. Stain susceptibility of composite and ceramic CAD/CAM blocks versus direct resin composites with different resinous matrices. Odontology. 2017;105(2):162–9.
46. Aydın N, Karaoğlanoğlu S, Oktay EA, Kılıçarslan MA. Investigating the color changes on resin-based CAD/CAM blocks. J Esthet Restor Dent. 2020;32(2):251–6.
47. Gentscheva G, Milkova-Tomova I, Buhalova D, Pehlivanov I, Stefanov S, Nikolova K, et al. Incorporation of the dry blossom flour of Sambucus Nigra L in the production of sponge cakes. Molecules. 2022;27(3):1124.
48. Tokuc M, Sukur EY. An in vitro evaluation of the effects of fluoride, CPP-ACP, or resin infiltration on discoloration caused by pediatric supplements. Quintessence Int. 2024;55(2):148–58.
49. Covey DA, Barnes C, Watanabe H, Johnson WW. Effects of a paste-free prophylaxis polishing cup and various prophylaxis polishing pastes on tooth enamel and restorative materials. Gen Dent. 2011;59(6):466–73. quiz 474–5.
50. Lund PS, Piotrowski TJ. Color changes of porcelain surface colorants resulting from firing. Int J Prosthodont. 1992;5(1):22–7.
51. Crispin BJ, Okamoto SK, Globe H. Effect of porcelain crown substructures on visually perceivable value. J Prosthet Dent. 1991;66(2):209–12.
52. Sasany R, Yilmaz B. Effect of stain brand and shade on color stability of stains applied on a CAD-CAM feldspathic ceramic. Odontology. 2022;110(3):452–9.
53. Bayindir F, Ozbayram O. Effect of number of firings on the color and translucency of ceramic core materials with veneer ceramic of different thicknesses. J Prosthet Dent. 2018;119(1):152–8.

Publisher's note