

Surface characterization and optical properties of zirconia-reinforced lithium silicate ceramics against different mouthwashes and thermocycling

Merve Benli¹, Müge Yargıcı Çağlayan², Beril Eker Gümüş³

¹ James B. Edwards College of Dental Medicine, Department of Oral Rehabilitation, Division of Removable Prosthodontics, MUSC, Charleston, SC, USA

² Istanbul University, Faculty of Dentistry, Department of Prosthodontics, Istanbul, Türkiye

³ Yıldız Technical University, Science and Technology Application and Research Center, Istanbul, Türkiye

Received: 14 June 2024

Accepted: 29 July 2024

Published: 16 August 2024

Correspondence:

Dr. Merve BENLİ

MUSC, Oral Rehabilitation, 173 Ashley Ave, MSC 507 Charleston, SC, USA.

E-mail: benlimerve@hotmail.com



How to cite this article:

Benli M, Yargıcı Çağlayan M, Eker Gümüş B. Surface characterization and optical properties of zirconia-reinforced lithium silicate ceramics against different mouthwashes and thermocycling. J Med Dent Invest 2024;5:e240334.

<https://doi.org/10.5577/jomdi.e240334>

Abstract

Aim: To evaluate color stability (ΔE_{00}), translucency (TP), and surface roughness (Ra) of zirconia-reinforced lithium silicate (ZLS) with lithium disilicate (LS) against different mouth rinses after thermocycling.

Methods: A total of 270 specimens were prepared: LS (IPS Emax CAD (group EC)), ZLS-1 (Vita Suprinity (group VS)), and ZLS-2 (Celtra Duo (group CD)). For each specimen, ΔE_{00} , TP, and Ra measurements were recorded with a clinical spectrophotometer (CM-3600A) and a 3D non-contact profilometer (AEP Nanomap-1000WLI), respectively, between baseline and after 10000 cycles of thermal cycling. Each group was divided into six subgroups (n=15) according to the immersion solution: five mouthwashes (Meridol, Klorhex, Listerine Cool Mint, Listerine Healthy White Natural Lemon&Salt, and Curasept ADS 212), and distilled water for 72 hours. Statistical analysis was performed by using a three-way robust ANOVA with Tukey HSD test ($\alpha=0.05$).

Results: Listerine Lemon&Salt and Cool Mint caused the highest ΔE_{00} and Ra values, while TP values of tested mouthwashes were similar ($p=0.051$). Group EC had the highest ΔE_{00} and Ra values with the lowest TP values against mouthwashes ($p<0.05$).

Conclusion: Prolonged use of mouthwashes may cause color change and increased surface roughness in LS more than ZLS. Patients should be advised to use alcohol-containing mouthwashes with caution in daily use.

Keywords: Mouthwashes, lithium disilicate, zirconium oxide, Vita Suprinity, Meridol

Introduction

The correct selection of restoration material plays an important role in ensuring clinical success (1). Computer-aided design and computer-aided manufacturing (CAD-CAM) systems allow dental clinicians to provide tooth-colored and esthetic restorations with various ceramics that have advanced optical and mechanical properties (2-5). Lithium disilicate-based ceramics (LS) are among the examples of materials of this type and have begun to be used frequently in today's dental clinics (6).

Zirconia-reinforced lithium silicate glass ceramic (ZLS) has been recently introduced to clinicians as a new monolithic CAD-CAM material for the fabrication of implant supra structures, crowns, onlays, and inlays (7, 8). ZLS has been launched as an advanced material that combines the optical properties of glass-ceramics (56-64% silica) and the mechanical properties of zirconia (8-14% zirconia) due to 10 wt% of zirconium dissolved in the glassy matrix (7, 9-11). ZLS is available in two forms: crystallized (Celtra Duo, Dentsply Sirona) and pre-crystallized (Vita Suprinity, Vita Zahnfabrik), and they contain lithium metasilicate crystals of different sizes (10, 12, 13). The crystal phase content of ZLS ceramic materials (40-50%) is lower than that of LS (70%) (14,15). In addition, these ZLS materials, which meet esthetic requirements with their improved translucency and different shade options, have optical and physical properties comparable to LS (14-16).

Optical properties of glass-ceramics such as translucency (TP) are critical from an esthetic point of view, and color stability is an important parameter for a long-lasting restoration (17, 18). Because color change may affect the quality of the restoration, discoloration has been reported to be one of the main clinical reasons (38%) for prosthesis replacement (19-21). Surface texture, as well as color and TP, play a role in achieving successful results in prosthetic dentistry (22). It has been reported in the literature that the optical properties of restorative materials are affected by the surface texture, material structure, thickness, background and material color, fabrication technique, adhesive material, and aging (23-25). The reflection and spread of light from a rough and irregular surface changes the color of the restoration (26). In addition, the rough surface has an impact on plaque accumulation, shade matching, wear on opposing teeth or restoration materials, and the patient's tactile perception. 27 Well-finished surfaces were reported to cause fewer technical and esthetic problems by giving the material harder, brighter, and more stable TP and color (3, 27). Therefore, to achieve clinical success, it is necessary to have information about the color stability, TP, and surface properties of ZLS ceramics.

Restorative materials are exposed to intrinsic and/or extrinsic factors that may be associated with discoloration during use in the oral environment. While external discoloration occurs as a result of absorption or adsorption of solutions that stain the oral environment, such as beverages (tea, coffee, etc.) and mouthwashes,

internal factors are related to the composition of restorative materials (28). Mouthwashes are widely used in various clinical situations to prevent periodontal diseases and improve oral health (29). Although these solutions have some clinical advantages, such as reducing the amount of supragingival plaque and the risk of gingivitis and preventing bad breath thanks to their bactericidal properties, they also have adverse effects, such as discoloration of restorative materials, erosion of teeth and mucosa, and taste disorder (28). Various components such as antimicrobial substances, salts, dyes, organic acids, and sometimes alcohol consisting of hydroxyl groups in the composition of mouthwashes are responsible for these adverse effects, and the duration of use of the mouthwash also affects the clinical results (28, 30). Therefore, although this is a criterion that should be taken into consideration when choosing restorative materials or antiseptic solutions in the aesthetic area, it appears that there are not enough studies in the literature evaluating the exposure of ZLS materials to various mouthwashes. Thus, this deficiency was one of the driving forces in the emergence of the current study.

Another feature that affects the clinical performance of restorative materials is aging, and this phenomenon is inevitable (17). Ceramic materials used in the production of restorations wear out during use, and in glass-ceramic materials, this occurs by dissolution during use, as they are predominantly made of silica glass structure with the inclusion of various other cations that disrupt the silica network (17). With this aim, thermal cycling, which simulates environmental variables in the mouth to reflect the clinical use of ZLS materials, was applied in this study for aging purposes with the combined effect of mouthwash solutions.

The objectives of this study were to investigate the color stability, TP, and surface roughness of two ZLS materials exposed to the aging process and different types of mouthwashes and to compare them with LS. The null hypotheses were that (i) ceramic type and mouthwash solution would not affect discoloration, (ii) ceramic type and mouthwash solution would not affect TP, (iii) ceramic type and mouthwash solution would not affect surface roughness.

Materials and Methods

In the present study, one type of LS (IPS Emax CAD (Ivoclar Vivadent, Schaan, Liechtenstein) (group EC), and two types of ZLS were evaluated, including Vita Suprinity (Vita Zahnfabrik, Bad Säckingen, Germany) (group VS), and Celtra Duo (Dentsply, Hanau-Wolfgang, Germany) (group CD). The details and compositions of the ceramic materials and mouthwashes used in the present study are displayed in Table 1. The sample size for the groups (n=72 per group) was determined based on an initial power analysis (PS software; Dupont and Plummer, 1997), which was estimated based on similar previous studies (5% significance level and mean gamma count with 80% power) (11, 17).

Table 1. List of materials used in the study*

Material	Product name	Chemical composition	Manufacturer	Translucency/ Shade	Batch number
Test material (milled lithium disilicate glass-ceramic)	IPS Emax CAD	%57-80 SiO ₂ , %11-19 Li ₂ O, K ₂ O ₃ , P ₂ O ₅ , ZrO ₂ , Al ₂ O ₃	Ivoclar Vivadent, Schaan, Leichtenstein	HT/A2	Y18855
Test material (milled zirconia-reinforced lithium silicate glass-ceramic)	Celtra Duo	%58 SiO ₂ , %18 Li ₂ O, %10 ZrO ₂ , P ₂ O ₅ , Al ₂ O ₃	Dentsply, Hanau-Wolfgang, Germany	HT/A2	16005716
Test material (milled zirconia-reinforced lithium silicate glass-ceramic)	Vita Suprinity	58-12 ZrO ₂ , %56-64 SiO ₂ , %15-21 Li ₂ O, %10>pigments	Vita Zahnfabrick, Bad Säckingen, Germany	HT/A2	51367
Gum protection mouthwash	MERIDOL	Aqua, xylitol, PVP, PEG-40 hydrogenated castor oil, olaflur, aroma, stannous fluoride, sodium saccharin, C.I. 42051	Colgate-Palmolive, Hamburg, Germany	-	PL03297A
Chlorhexidine gluconate	Klorhex	0.12% chlorhexidine gluconate in a base containing water, 11.6% alcohol, glycerin, PEG-40 sorbitan diisostearate, flavor, sodium saccharin, and FD&C Blue No.1	Drogsan, Istanbul, Türkiye	-	23645
Conventional mouthwash	LISTERINE Cool Mint	Thymol, eucalyptol, methyl salicylate, and menthol. Inactive ingredients: water, ethanol (21.6%), poloxamer 407, sorbitol solution (70%), flavour, sodium saccharin, benzoic acid, zinc chloride, sodium benzoate and green 3	Johnson & Johnson New Jersey, NJ, USA	-	G015C
Whitening mouthwash	LISTERINE Healthy White Natural Lemon & Salt	Thymol, eucalyptol, menthol, and sodium fluoride 0.02% (0.01% w/v fluoride ion). Inactive ingredients: water, ethanol (14.58%), poloxamer 407, sorbitol solution (70%), sucralose, sodium saccharin, tetra potassium pyrophosphate, pentasodium triphosphate, sodium chloride, citric acid, flavour, sodium benzoate	Johnson & Johnson New Jersey, NJ, USA	-	171118C2 00B
Protective mouthwash	Curasept ADS 212	Purified water, xylitol 16041, chemophor RH40, propylene glycol, trisodium citrate, 0,12% chlorhexidine digluconate, ascorbic acid, symperonic F127, sodium metabisulfite, PVP/VA copolymer, blue FD&C, peppermint M644, anethole, menthol, mint green, essential oil of cloves, essential oil of cinnamon, sodium benzoate	CURADEN HEALTHCARE S.p.A., Saronno VA, Italy	-	284982002 983

*Written followed by the information of the manufacturers

Specimens Preparation

A total of 270 square-shaped specimens (90 samples of each ceramic) (10 mm×10 mm×1.2 mm) were prepared with a low-speed diamond saw (Isomet 4000, Buehler, Lake Bluff, IL, USA) under a water-cooling system at a speed of 2500 rpm and a feeding rate of 14.4 mm/min, and the thickness was measured using a digital caliper (Digimatic Micrometer; Mitutoyo Corp., Tokyo, Japan).

These specimens were divided into six subgroups according to the mouthwash type (MERIDOL (Colgate-Palmolive, Hamburg, Germany), Klorhex (Drogsan, Istanbul, Türkiye), LISTERINE Cool Mint (Johnson & Johnson, New Brunswick, NJ, USA), LISTERINE Healthy White Natural Lemon&Salt (Johnson & Johnson, New Brunswick, NJ, USA), Curasept ADS 212 (CURADEN HEALTHCARE S.p.A., Saronno, VA, Italy) and distilled water for the control group. Samples of groups EC and VS were crystallized in a ceramic furnace (Programat

EP5000; Ivoclar Vivadent, Schaan, Liechtenstein) at a temperature of 840°C for about 8 minutes and 850°C for 10 minutes based on the manufacturer's recommended crystallization program, respectively.

One side of each sample was designated as the test surface, and the remaining surfaces were covered with transparent nail polish (Nail Enamel-301, Glass Effect, Flormar, Milano, Italy). Surfaces were finished and polished using silicon carbide grinding paper (Buehler-Met II Silicon carbide grinding paper P400/600, Buehler, Lake Bluff, IL, USA) from 600 to 1200 grit under running water at 300 rpm (Mecatech 264, Presi, Eybens, France), followed by the application of polishing paste (Renfert Polish LiSi₂, Renfert GmbH Company, Hilzingen, Germany). Finishing and polishing were performed in one direction with standard pressure, time, and the same operator, according to the manufacturers' instructions. The samples were then thoroughly cleaned ultrasonically for 15 minutes (Eurosonic Micro, Euronda, Vicenza, Italy) and air-dried for 30 seconds. The surfaces were checked for cracks or irregularities using a magnifying loupe (HR ×2.5, 420 mm/16", Heine, Germany), and a final check for the dimensions of the samples was performed using a digital caliper.

Measurements for Optical Properties

Optical measurements of all samples were made at the baseline, after the aging process and after being exposed to mouthwash.

These measurements were performed in "tooth single" mode using a clinical spectrophotometer (CM-3600A; Konica Minolta Inc, Tokyo, Japan) according to CIEDE2000 color coordinates. The interval wavelength at which the measurements were taken was between 360 and 740 nm in an 8 mm diameter illumination area. Before the measurements, the spectrophotometer was calibrated at the intervals specified by the manufacturer. Measurements were performed on the polished surfaces of the specimens using D65 standard illumination under an observer angle of 10° and a light source angle of 45° (22). The same time of day was preferred for measurements, and each sample was measured three times on two different backgrounds. Readings were carried out by an expert operator and average values were calculated by the same operator. The CIELAB values were recorded on both white (W) ($L^* = 94.6$, $a^* = 0.2$, $b^* = -0.8$) and black (B) ($L^* = 2.3$, $a^* = 0.5$, $b^* = 2.1$) backgrounds. Further color measurements were performed on a neutral gray background, and the TP was determined as the color difference (ΔE_{00}) between measurements against W and B backgrounds. Color difference values obtained under experimental conditions were calculated with the following formula of CIEDE2000 (ΔE_{00}) (31):

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

The parametric factors of the CIEDE2000 color difference formula were considered as 1. The perceptibility threshold was accepted as $\Delta E_{00} \leq 0.81$, and the acceptability threshold was accepted as $\Delta E_{00} > 1.77$ (32).

Surface Roughness Measurements and Surface Observation

The surface roughness (Ra) values of the study surfaces were measured by the 3D non-contact profilometer (AEP Nanomap-1000WLI; AEP Technology, Santa Clara, CA, USA) with an optical resolution of 550 nm. The Ra value, which is the arithmetic mean value of the absolute values of the roughness profile of the folds (surface heights) followed from top to bottom, was measured for this aim (33).

Values of the Ra were calculated for each group and subgroup at the baseline, before and after thermocycling and mouthwash simulation. The average of Ra values was computed with SPIP software (Image Metrology A/S, Lyngby, Denmark) using three single individual measurements, according to ISO 4287.

Further evaluation of the structural surface topography of each group was performed under a scanning electron microscope (SEM) (Carl Zeiss EVO LS 10; Carl Zeiss NTS, Oberkochen, Germany) at 250x magnification after sputter coating with gold.

Aging process

Samples underwent an aging process with a 30 s dwell and 6 s transition time before mouthwash simulation by using a thermocycling machine under the condition of 5-55°C with a heating and cooling system by a programmable logic (Automated Thermocycling Machine; Gökçeler Machines, Sivas, Türkiye). Each specimen was tested for 10,000 cycles to simulate approximately one year of in vivo use (34).

Mouthwash simulation

Specimens of each ceramic group were divided into five mouthwash groups (MERIDOL, Klorhex, LISTERINE Cool Mint, LISTERINE Healthy White Natural Lemon&Salt, Curasept ADS 212) and distilled water for the control (n=15).

Mouthwash solutions were kept in vials with a cover to prevent evaporation at 37°C for the test period of 72 hours, which is equivalent to six years of mouthwash use when the solution is used twice a day for one minute each time (35).

All the specimens were immersed in 20 ml mouthwash or distilled water for 2 minutes, and test solutions were changed twice daily.

Statistical analysis

Statistical analysis was carried out using the WRS2 package with R Program (R Core Team; R Foundation for Statistical Computing, Vienna, Austria).

Conformity with normal distribution was examined with skewness - kurtosis (± 2) values. A three-way robust ANOVA (analysis of variance) test was used to compare TP values that did not comply with normal distribution according to solution, material, and time, and multiple comparisons were performed with Bonferroni Correction.

Three-way ANOVA was used to compare L, a, b, and ΔE values, and the Tukey HSD test was applied for multiple comparisons. Analysis results were presented as median (minimum-maximum). The significance level was considered as $p < 0.05$.

Results

ΔE_{00}

For color difference ΔE_{00} , a statistically significant interaction was observed among the group, solution, and time ($p < 0.001$) (Table 2).

All groups subjected to the aging process showed greater discoloration than after immersing mouthwash solutions in all groups ($p < 0.05$). A significant difference between the ΔE_{00} values of the groups was detected, regardless of the solution and time effect ($p < 0.001$). Average ΔE_{00} values varied depending on the solutions ($p = 0.020$), and the lowest value was obtained in distilled water (0.54 ± 0.32) (Table 3).

Average ΔE_{00} values differed according to material and time ($p < 0.001$), and the mouthwash application of the group VS revealed the lowest average value (0.56 ± 0.33) (Table 3).

Table 2. Comparison of ΔE_{00} values by group, solution and time

	SS	DF	MS	F	p	PES
Group	5.163	2	2.581	52.04	<0.001	0.243
Solution	0.677	5	0.135	2.730	0.02	0.04
Time	14.07	1	14.07	283.65	<0.001	0.467
GroupxSolution	0.952	10	0.095	1.92	0.042	0.056
GroupxTime	0.925	2	0.463	9.32	<0.001	0.054
SolutionxTime	0.428	5	0.086	1.72	0.128	0.026
GroupxSolutionxTime	2.465	10	0.247	4.97	<0.001	0.133

SS: Sum of squares; DF: Degrees of freedom; MS: Mean squares; F: Test statistics; PES: Partial eta squared

Table 3. Descriptive statistics of ΔE_{00} values and multiple comparison results

Group	Solution	Thermal cycling	Mouthwash	Total
Celtra Duo	Cool Mint	1.08 ± 0.18	0.80 ± 0.16	0.96 ± 0.26
	Curasept	0.86 ± 0.08	0.56 ± 0.16	0.69 ± 0.14
	Klorhex	0.93 ± 0.11	0.59 ± 0.24	0.75 ± 0.32
	Lemon/salt	1.06 ± 0.17	0.74 ± 0.21	0.95 ± 0.28
	Meridol	0.95 ± 0.18	0.64 ± 0.12	0.81 ± 0.21
	Distilled water	0.70 ± 0.12	0.62 ± 0.20	0.66 ± 0.16
	Total	0.94 ± 0.19	0.60 ± 0.19	0.77 ± 0.26
Emax CAD	Cool Mint	1.16 ± 0.13	0.73 ± 0.27	0.94 ± 0.30
	Curasept	1.02 ± 0.11	0.52 ± 0.28	0.78 ± 0.33
	Klorhex	1.08 ± 0.25	0.58 ± 0.27	0.80 ± 0.42
	Lemon/salt	1.14 ± 0.12	0.72 ± 0.29	0.87 ± 0.34
	Meridol	1.12 ± 0.11	0.62 ± 0.22	0.82 ± 0.27
	Distilled water	1.06 ± 0.13	0.35 ± 0.25	0.72 ± 0.35
	Total	1.11 ± 0.15	0.58 ± 0.29	0.85 ± 0.35
Vita Suprinity	Cool Mint	0.99 ± 0.24	0.54 ± 0.15	0.66 ± 0.39
	Curasept	0.62 ± 0.08	0.36 ± 0.19	0.42 ± 0.18
	Klorhex	0.67 ± 0.12	0.44 ± 0.22	0.56 ± 0.17
	Lemon/salt	0.87 ± 0.30	0.48 ± 0.53	0.63 ± 0.44
	Meridol	0.77 ± 0.11	0.46 ± 0.22	0.59 ± 0.28
	Distilled water	0.51 ± 0.28	0.32 ± 0.46	0.40 ± 0.41
	Total	0.72 ± 0.26	0.41 ± 0.32	0.56 ± 0.33
Total	Cool Mint	0.95 ± 0.25	0.59 ± 0.26	0.75 ± 0.37
	Curasept	0.82 ± 0.29	0.50 ± 0.19	0.65 ± 0.36
	Klorhex	0.85 ± 0.33	0.52 ± 0.24	0.71 ± 0.34
	Lemon/salt	0.95 ± 0.26	0.57 ± 0.36	0.75 ± 0.32
	Meridol	0.9 ± 0.2	0.55 ± 0.25	0.73 ± 0.29
	Distilled water	0.79 ± 0.23	0.39 ± 0.33	0.54 ± 0.32
	Total	0.92 ± 0.26	0.53 ± 0.28	0.73 ± 0.34

The mean color difference (ΔE_{00}) values ranged from 0.32 ± 0.19 to 1.16 ± 0.13 after the aging process and immersing mouthwash solutions (0.51 ± 0.28 - 1.16 ± 0.13 for the aging process; 0.32 ± 0.19 - 0.84 ± 0.16 for mouthwash) (Table 3). Mean ΔE_{00} values of all groups except the group EC (0.85 ± 0.35) are below the visual perceptability threshold value ($\Delta E_{00} \leq 0.81$), and all specimens showed clinically acceptable levels of color change ($\Delta E_{00} > 1.77$).

TP

For TP, the solution's main effect was not found to be statistically significant on TP median values ($p = 0.051$), while a significant interaction was detected among the group and time ($p < 0.05$) (Table 4). The highest TP value was found in the group VS ($20.1(12.42-23.51)$) and the lowest TP value belonged to group EC ($15.66(12.25-21.45)$) (Table 5).

Solution and material interaction was found to be statistically significant on TP average values ($p=0.001$). The highest average value was found in group VS with Meridol mouthwash material (20.97 (16.43- 23.51)) (Table 5).

Material and time interaction was found to be statistically significant on TP mean values ($p=0.002$). The highest average TP value was obtained after mouthwashing in the group VS (20.64 (12.82-23.51)), and the lowest value occurred in the group EC (15.48 (12.25-19.1)) after the aging process (Table 5).

Table 4. Comparison of translucency parameters according to mouthwash, material and time

	Q	p
Solution	13.192	0.051
Material	352.237	<0.001
Time	27.346	0.001
SolutionxMaterial	48.421	0.001
SolutionxTime	4.659	0.931
MaterialxTime	20.438	0.002
SolutionxMaterialxTime	10.862	0.973

Q: Three-Way Robust Anova test statistics

Table 5. Descriptive statistics and multiple comparison results of translucency values by solution, material and time.

Material					
Mouthwash	Time	Celtra Duo	Emax CAD	Vita Suprinity	Total
Meridol	Before	17.88 (16.54-19.52)	15.5 (13.22-18.65)	21.33 (17.17-23.2)	17.88 (13.22-23.2)
	After TC	17.59 (16.43-19.4)	14.93 (12.79-18.27)	20.09 (16.43-21.81)	17.59(12.79-21.81)
	After MW	19.31 (18.18- 20.85)	15.96 (13.58-19.64)	21.18 (17.19-23.51)	19.3 (13.58-23.51)
	Total	18.21 (16.43-20.85) ^{ABC}	15.62 (12.79-19.64) ^{EFH}	20.97 (16.43-23.51) ^{DG}	18.09 (12.79-23.51)
Klorhex	Before	16.95 (14.86-18.29)	16.02 (13.35-18.8)	19.83 (18.88-22.88)	17.26(13.35-22.88)
	After TC	17.27 (14.82-18.52)	15.49 (12.54-18.25)	20.1 (16.43-23.14)	17.39(12.54-23.14)
	After MW	18.61 (15.39-19.33)	14.66 (13.15-21.45)	20.73 (19.82-23.18)	18.79(13.15-23.18)
	Total	17.23 (14.82-19.33) ^{ABH}	15.49 (12.54-21.45) ^{EFH}	20.17 (16.43-23.18) ^G	17.76 (12.54- 23.18)
Cool Mint	Before	17.88 (17.26-18.45)	15.48 (14.44-16.27)	19.31 (13.91-22.63)	17.27(13.91-22.63)
	After TC	18.3 (16.43-18.97)	14.84 (14.12-16.43)	17.63 (13.32-21.96)	16.43(13.32-21.96)
	After MW	19.94 (19.16-20.22)	15.07 (14.29-16.18)	19.14 (14.26-23.41)	19.13(14.26-23.41)
	Total	18.53 (16.43-20.22) ^{ABCD}	15.22 (14.12-16.43) ^E	19.14 (13.32-23.41) ^{ABCEFGH}	17.27 (13.32- 23.41)
Lemon/salt	Before	17.77 (17.35-19.65)	15.67 (13.98-18.55)	19.96 (18.06-22.95)	17.98(13.98-22.95)
	After TC	18.14 (16.43-19.72)	15.56 (13.53-17.89)	18.35 (12.42-22.42)	17.91(12.42-22.42)
	After MW	19.68 (18.86-20.43)	16.36 (14.42-18.88)	21 (12.82-22.74)	19.45(12.82-22.74)
	Total	18.55 (16.43- 20.43) ^{BCD}	15.85 (13.53-18.88) ^{EFH}	20.08 (12.42-22.95) ^{CDG}	18.09 (12.42- 22.95)
Curasept	Before	17.09 (16.11-18.04)	15.48 (12.35-18.19)	20.4 (18.65-21.82)	17.28(12.35-21.82)
	After TC	17.91 (16.43-18.57)	14.99 (12.25-17.39)	19.28 (16.43-20.87)	17.39(12.25-20.87)
	After MW	19.25 (16.43-19.97)	14.98 (12.45-17.74)	20.77 (19.9-21.43)	19.25(12.45-21.43)
	Total	17.89 (16.11- 19.97) ^{ABC}	15.13 (12.25-18.19) ^{EF}	20.26 (16.43-21.82) ^G	17.89 (12.25- 21.82)
Distilled water	Before	18.12 (15.2-19.37)	16.74 (15.79-19.14)	18.39 (13.84-20.62)	18.01(13.84-20.62)
	After TC	18.36 (15.73-19.87)	16.23 (15.01-19.1)	19.71 (16.17-21.11)	18.08(15.01-21.11)
	After MW	19.86 (16.4-20.9)	16.86 (15.83-20.57)	20.34 (15.85-20.78)	19.7 (15.83-20.9)
	Total	18.53 (15.2- 20.9) ^{ABCDG}	16.74 (15.01- 20.57) ^{AFH}	19.88 (13.84-21.11) ^{ABCDG}	18.35 (13.84- 21.11)
Total	Before	17.79(14.86-19.65) ^A	15.86(12.35-19.14) ^C	19.96 (13.84-23.2) ^{BD}	17.72 (12.35- 23.2) ^a
	After TC	17.68(14.82-19.87) ^A	15.48(12.25-19.1) ^C	19.58 (12.42-23.14) ^B	17.54 (12.25- 23.14) ^a
	After MW	19.45(15.39-20.9) ^B	15.85(12.45-21.45) ^C	20.64 (12.82-23.51) ^D	19.23 (12.45- 23.51) ^b
	Total	18.2 (14.82-20.9) ^c	15.66(12.25-21.45) ^b	20.1 (12.42-23.51) ^a	17.98 (12.25- 23.51)

Median (minimum - maximum); a-c: There is no difference between main effects with the same letter; AH: There is no difference between interactions with the same letter. TC: Thermal cycling; MW: Mouthwashing

Ra

For Ra, a statistically significant interaction was found among the group, solution, and time ($p=0.022$), while the effect of the material on Ra values was not found to be significant ($p=0.051$) (Table 6). The highest Ra median value was obtained after group EC was immersed in Lemon/Salt mouthwash (0.27) and after immersing in Cool Mint mouthwash (0.27) (Table 7).

The average Ra values obtained after the baseline measurements (0.2 (0.2-0.2)) of all three materials were different from the Ra values obtained after immersing in mouthwash solutions (0.23 (0.2-0.3)) ($p<0.05$) (Table 6).

Table 6. Comparison of Ra (surface roughness) values according to material, solution and time

	Q	p
Material	32.905	0.041
Solution	92.147	<0.001
Time	307.211	0.001
MaterialxSolution	27.058	0.051
MaterialxTime	7.705	0.026
SolutionxTime	94.073	0.001
MaterialxSolutionxTime	25.165	0.022

Q: Three-Way Robust Anova test statistics

Profile evaluation and surface observation

Optical profilometry images of the groups based on the solution were described in Figures 1, 2, and 3. After mouthwashing with distilled water, all groups' surfaces appeared relatively smooth and uniform. Regarding 2D

and 3D observations and profile evaluation of the surfaces after mouthwashing, Lemon/Salt and Meridol displayed the most irregular surface among all solutions for groups CD (Fig. 1) and EC (Fig. 2). It was also observed that the solution that caused the formation of the most irregular surfaces for group VS was Lemon/Salt (Fig. 3).

Table 7. Descriptive statistics and multiple comparison results of Ra (surface roughness) values by solution, material and time

Material	Time	Solution						Total
		Distilled water	Lemon/Salt	Klorhex	Curasept	Cool Mint	Meridol	
Celtra Duo	Before	0.2 (0.2-0.2) ^{ABCDE}	0.21(0.2- 0.2) ^{ABCDE}	0.21(0.2-0.2) ^{ABCDEF}	0.21 (0.2- 0.2) ^{ABCDEF}	0.2 (0.2- 0.2) ^{ACD}	0.2 (0.2-0.2) ^{ACD}	0.2 (0.2-0.2) ^A
	After MW	0.21 (0.2-0.2) ^{ABCDE}	0.25(0.2-0.3) ^{ABCDEF}	0.23(0.20.3) ^{ABCDEF}	0.23(0.2- 0.3) ^{ABCDEF}	0.23(0.2-0.3) ^{ABCDEF}	0.24 (0.2-0.3) ^{DEFH}	0.22 (0.2-0.3) ^B
	Total	0.21 (0.2-0.2)	0.23(0.2-0.3)	0.22 (0.2-0.3)	0.22 (0.2-0.3)	0.21 (0.2-0.3)	0.23 (0.2-0.3)	0.21 (0.2-0.3)
Emax CAD	Before	0.21 (0.2-0.2) ^{ABCDE}	0.21 (0.2-0.2) ^{ABCDE}	0.21(0.2- 0.2) ^{ABCDE}	0.2 (0.2- 0.2) ^{ACD}	0.2 (0.2-0.2) ^{AC}	0.2 (0.2-0.2) ^{ABCDE}	0.2 (0.2-0.2) ^A
	After MW	0.21 (0.2-0.2) ^{ABCDE}	0.27 (0.3-0.3) ^{HI}	0.22(0.2-0.2) ^{ABCDEF}	0.23 (0.2- 0.2) ^{ABCDEF}	0.27 (0.2- 0.3) ^{GI}	0.26 (0.3-0.3) ^{FGHI}	0.25 (0.2-0.3) ^B
	Total	0.21 (0.2-0.2)	0.24 (0.2-0.3)	0.21(0.2-0.2)	0.21 (0.2-0.2)	0.23 (0.2-0.3)	0.24 (0.2-0.3)	0.21 (0.2-0.3)
Vita Suprinity	Before	0.2 (0.2-0.2) ^{ABCDE}	0.2 (0.2- 0.2) ^{ACD}	0.2 (0.2- 0.2) ^A	0.2 (0.2- 0.2) ^{ACD}	0.2 (0.2- 0.2) ^A	0.19(0.2-0.2) ^A	0.2 (0.2- 0.2) ^A
	After MW	0.21 (0.2- 0.2) ^{ABCDEF}	0.25 (0.2-0.3) ^{BEFGHI}	0.21 (0.2- 0.3) ^{ABC}	0.22 (0.2- 0.3) ^{ABCDEF}	0.23(0.2- 0.3) ^{ABCDEF}	0.25(0.2-0.3) ^{BCDEF}	0.22 (0.2- 0.3) ^B
	Total	0.2 (0.2-0.2)	0.22 (0.2- 0.3)	0.2 (0.2- 0.3)	0.21 (0.2- 0.3)	0.21 (0.2-0.3)	0.21 (0.2-0.3)	0.21 (0.2- 0.3)
Total	Before	0.2 (0.2- 0.2) ^A	0.21 (0.2- 0.2) ^{AB}	0.2 (0.2-0.2) ^A	0.2 (0.2-0.2) ^A	0.2 (0.2-0.2) ^A	0.2 (0.2-0.2) ^A	0.2 (0.2-0.2)
	After MW	0.21 (0.2- 0.2) ^{AB}	0.25 (0.2-0.3) ^C	0.22 (0.2- 0.3) ^{BD}	0.23 (0.2- 0.3) ^{DE}	0.24 (0.2- 0.3) ^{CE}	0.25 (0.2- 0.3) ^C	0.24 (0.2-0.3)
	Total	0.18 (0.2-0) ^a	0.18 (0.3-0) ^b	0.17 (0.3-0) ^{bc}	0.18 (0.3-0) ^{abc}	0.18 (0.3-0) ^{abc}	0.18 (0.3-0) ^{bc}	0.17 (0.3-0)

Median(minimum-maximum); a-c: There is no difference between main effects with the same letter; A-I: There is no difference between interactions with the same letter. MW: Mouthwashing

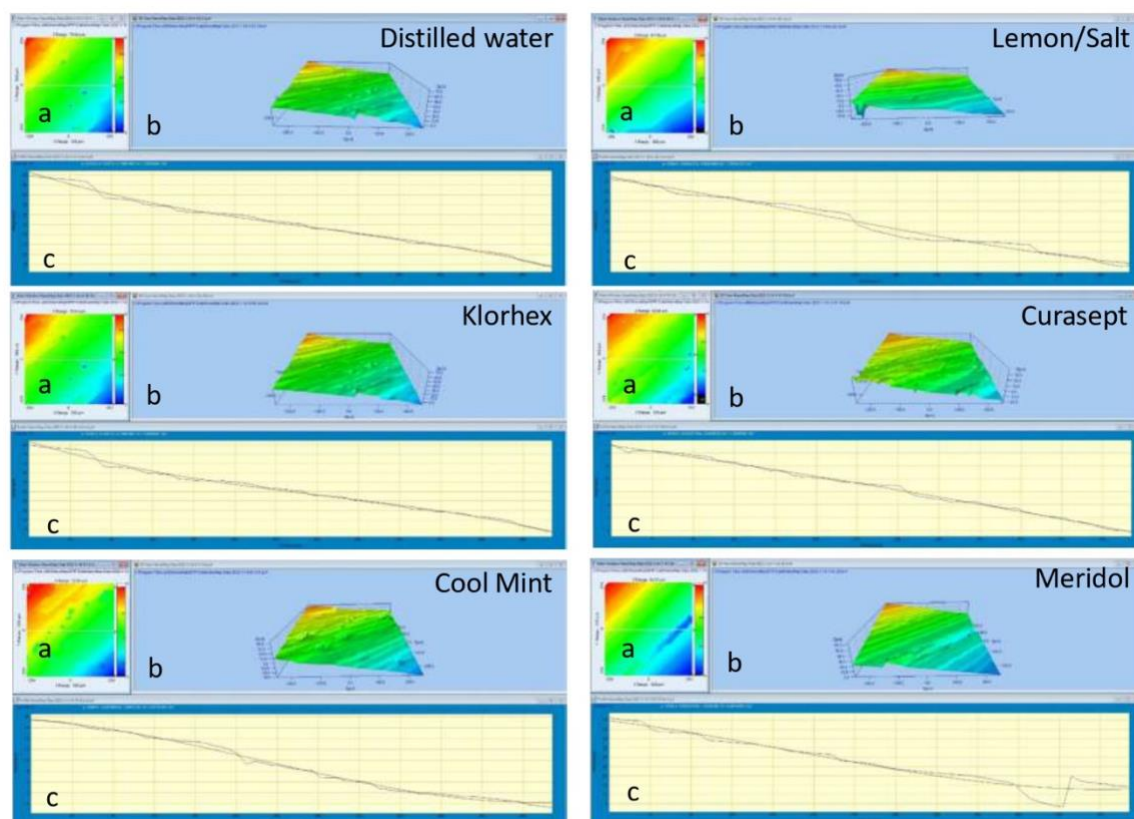


Figure 1. Optical profilometry images showing the 2D (a), 3D surface topography (b) and the profile roughness (c) for the line of Celtra Duo samples after immersing in selected mouthwashes.

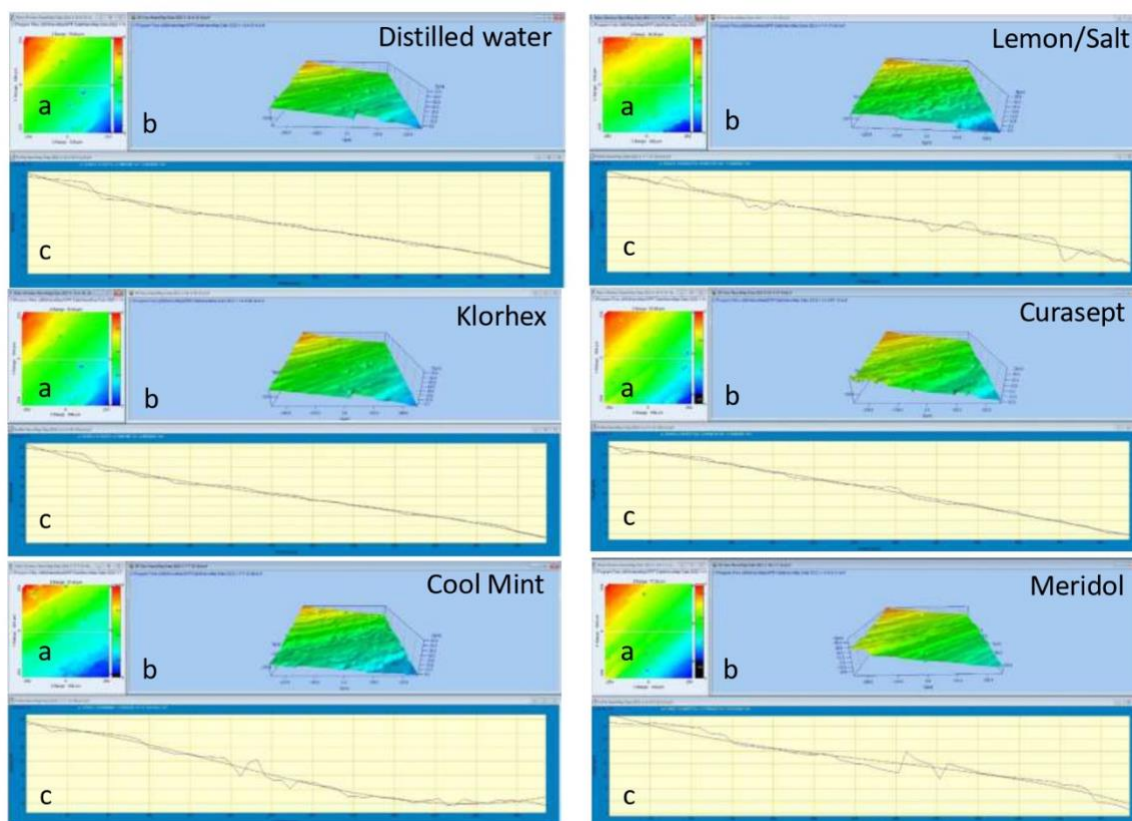


Figure 2. Optical profilometry images showing the 2D (a), 3D surface topography (b) and the profile roughness (c) for the line of Emax CAD samples after immersing in selected mouthwashes.

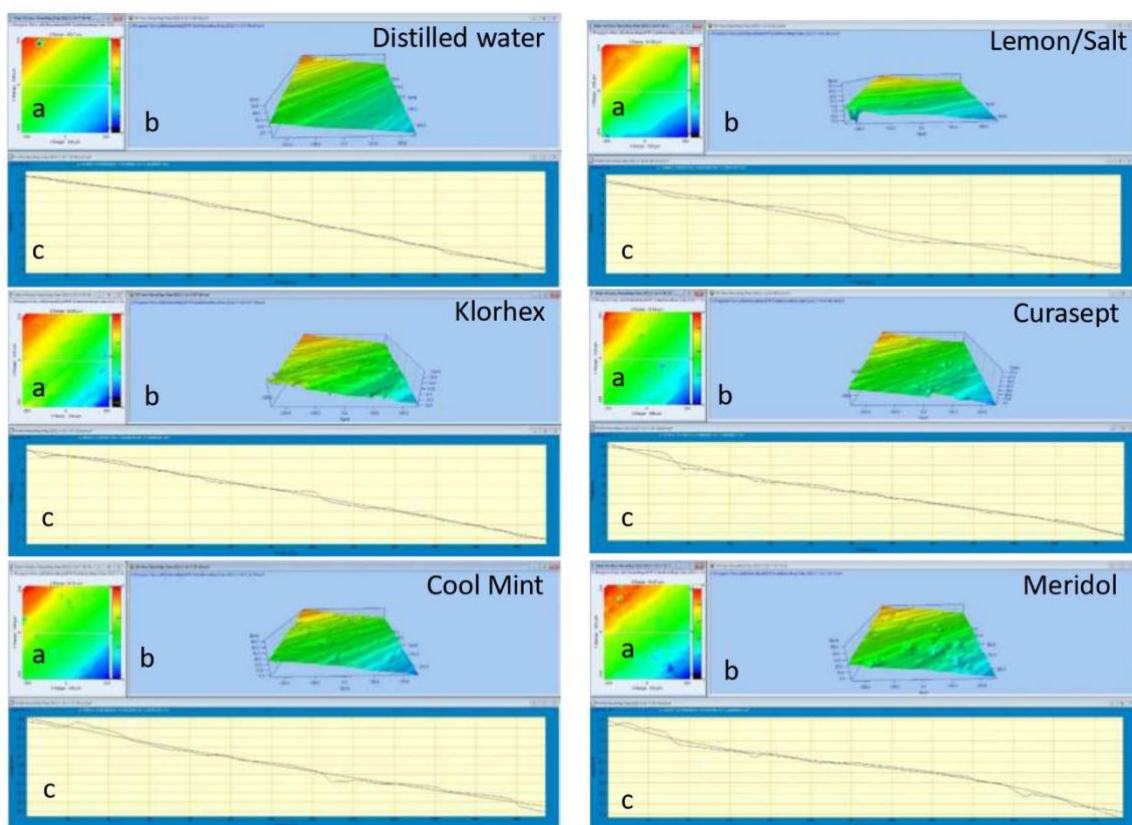


Figure 3. Optical profilometry images showing the 2D (a), 3D surface topography (b) and the profile roughness (c) for the line of Vita Suprinity samples after immersing in selected mouthwashes.

Discussion

The present study evaluated the performance of two different ZLS materials based on ΔE_{00} , TP, and Ra by comparing them with LS. The overall results of this study showed mouthwash solution and ceramic type were effective on ΔE_{00} and Ra values, while TP values were affected only by the material type. Thus, while the first and second null hypotheses of this study were rejected, the third null hypothesis was partially rejected.

Color stability during the clinical survival period of the prosthetic restoration is as important as the mechanical strength of the dental material, and changes in the color affect the lifespan and quality of the restoration (36). There are studies in the literature evaluating the effect of various coloring solutions (artificial saliva, orange juice, cola, coffee, and red wine) on the color of dental materials, but studies investigating the discoloring effect of mouthwashes on prosthetic dental materials are less common (37-41). In these studies, it is observed that they generally examine the effects of mouthwashes on composites, compomers, acrylic resins, resin-modified glass ionomers, and hybrid composites, and it is understood that there are not enough studies on LS ceramics (40). For this reason, in the present study, the effect of new-generation mouthwashes on both discoloration and optical and surface properties of LS and ZLS CAD/CAM restorative materials was comprehensively investigated.

Mouthwashes are frequently used to eliminate the pathogenic microorganisms that cause tooth decay, periodontal diseases, and bad breath, and their duration of use varies depending on the patient and indication (42). The duration of use of mouthwashes is increased in patients undergoing chemotherapy and radiotherapy, in the presence of osteoradionecrosis and osteonecrosis, in the treatment of osteomyelitis, and in cases where patients with mental or physical disabilities can't maintain oral hygiene (43). Considering the use of mouthwashes in daily life, it has been reported that a one-year application of mouthwash for one minute twice a day is equivalent to a 12-hour test evaluation period (44). In this study, to evaluate the long-term effect of mouthwashes, the samples were kept in the mouthwashes for 72 hours, in other words, equivalent to 6 years of restoration clinical use.

Besides mouthwashes, the clinical performance of dental restorations is affected by aging, and thermal aging of dental restorations is a natural phenomenon (17). The artificial aging method with thermal cycling, which reflects the temperature changes in the oral environment, is one of the most common methods used in experimental studies, and all samples in our study were first subjected to thermal cycling and then mouthwashing to imitate the oral environment (45). It has been reported in the literature that the thermal cycle applied for 10000 cycles between 5-55 °C temperatures corresponds to 1 year of restoration in

clinical use, and this period was taken as the basis in the current study (46).

In all the ceramic groups, immersion in LISTERINE Cool Mint and Lemon&Salt led to the highest discoloration, and distilled water provided the lowest ΔE_{00} values for all groups (Table 3). In the present study, while there was no difference between the ΔE_{00} values in the groups CD and EC after immersing mouthwashes, the lowest value was measured in the group VS and all values were below the visual perceptibility threshold value ($\Delta E_{00} \leq 0.81$). The ΔE_{00} findings of the present study about Listerine Cool Mint (0.75 ± 0.37) and Lemon&Salt (0.75 ± 0.32) mouthwashes agreed with the findings of other previous studies that evaluated all ceramics and reported greater discoloration than after being immersed in Klorhex (22). In other studies where resin nano ceramics, polymer-infiltrated ceramic networks, feldspathic ceramics, LS, and zirconia were evaluated, it was observed that results parallel to the present study were obtained and the most discoloration was in the Listerine mouthwashes than chlorhexidine solutions (22, 47). This difference could be attributed to the alcohol content of Listerine mouthwashes (21.6% ethanol, LISTERINE Cool Mint; 14.58% ethanol, LISTERINE Lemon&Salt) as some studies have reported that mouthwashes with high alcohol content increase color changes on bioceramic material due to alcohol having a higher absorption and solubility effect on the material by causing chemical changes such as volumetric change, hydrolysis, and oxidation (22, 40, 48). It is also stated in the literature that mouthwashes not only have high alcohol content and low pH values but also contain preservative and coloring components, which cause color changes in the restorative materials. Thus, the discoloration or esthetical properties of CAD/CAM all ceramic materials may be evaluated in future studies based on different pH values.

Another reason why Listerine Lemon&Salt causes more discoloration than other mouthwashes may be the sodium fluoride (NaF) content (0.02%) that is not found in other mouthwashes. NaF is added to the mouthwash formula as an anti-caries ingredient, and it was stated that the fluoride content caused changes in the surface roughness and color of different dental ceramics (49-51). Although this NaF content supports the discoloring effect of Listerine Lemon&Salt than other evaluated mouthwashes in the present study, no difference was found in the color change effect of Listerine Cool Mint and Lemon&Salt, warranting future studies.

There are not enough studies to allow comparing the results of the current study with Meridol, which was included in this study and contains amine fluoride and stannous fluoride as active ingredients (Table 1). In the present study, it was measured that Meridol produced a lower total ΔE_{00} value (0.73 ± 0.29) than Listerine group mouthwashes (Cool Mint, 0.75 ± 0.37 ; Lemon&Salt, 0.75 ± 0.32) and higher ΔE_{00} values than Klorhex (0.71 ± 0.34) and Curasept (0.65 ± 0.36) mouthwashes for all study groups. In a study with a similar setup to the current study evaluating composite materials, it was found that the color change caused by the Meridol group was

significantly less than other solutions (Listerine Total Care Zero and Andorex), and the color change caused by mouthwash groups other than the Meridol was not statistically different from the control group (52). In this study, excluding the control group, the Curosept group was determined to have the lowest total ΔE_{00} value (0.65 ± 0.36) compared to the solutions. A statistically significant difference was detected between the total ΔE_{00} values of the ceramic groups, and the highest discoloration was measured in the group EC (0.85 ± 0.35) ($p < 0.001$). This result may be thought to be due to the difference in the content of LS ceramics from ZLS (3). Another point worth noting is that thermal cycling (0.92 ± 0.26) caused more color change than exposure to mouthwash (0.53 ± 0.28) in all groups, regardless of the material. This can be attributed to the knowledge that small-sized particles show changes in distribution due to the decrease in particles after aging, which may be related to changes on the surface (53). Therefore, it is recommended that clinicians pay attention to periodic follow-ups to clinically reduce the discoloration problems of restorations produced from LS and ZLS materials.

The TP value of the material affects the aesthetics of dental ceramics as much as the color (53). It has been shown in the literature that the TP value of human teeth varies approximately between 15 and 19 at 1 mm thickness, and the TP values of restorative materials can reach up to 25 (54). The initial average TP values of the samples prepared with 1.2 mm thickness in this study were measured as 17.79 (14.86-19.65) for Celtra Duo, 15.86 (12.35-19.14) for Emax CAD and 19.96 (13.84-23.2) for Vita Suprinity, respectively (Table 5). When the TP values obtained from all materials included in the study were compared, no statistically significant difference was seen at the beginning and after the thermal cycle, while the values after immersion in mouthwash were found to have a higher TP distribution. This may be attributed to the effects of the mouthwash ingredients, pH levels, or alcohol content on the material, and is consistent with the results of studies from Soygun et al. and Lee et al. (40, 47).

In the current study, while the main effect of the mouthwash solution on TP values was not found to be statistically significant, the material effect was found to be significant ($p < 0.001$). TP median values obtained from all materials differ from each other, and the lowest value was measured in the group EC after mouthwashing (15.66 (12.25-21.45)) (Table 5). This situation is compatible with the data obtained from various studies that ZLS material shows higher TP than resin nano-ceramics, polymer-infiltrated ceramics, feldspathic ceramics, and LS ceramics (5, 55, 56). TP values of dental ceramics are affected by factors such as the crystal structure, dimensions, structural differences, pigments, size and distribution of defect areas contained in the material, and the crystal size of ZLS has been reported to be 4 to 8 times smaller than the crystals contained in LS (3, 57-59). Although TP depends on the properties of the material, surface roughness, and thickness also affect this parameter (3). In Kanchanasavita et al.'s study, it was reported that reducing the thickness of the

material increased the TP value (60). Therefore, in this study, the thickness of the samples was determined as 1.2 mm to be similar to the prosthetic restoration thicknesses applied in the clinic. The processes applied to the surface of the ceramic material as well as the material thickness affect its TP (54). To prevent this effect from affecting the study results and to ensure standardization, mechanical polishing was applied to the surfaces of the samples. As there are studies in the literature reporting that LS and ZLS restorations with polished surfaces exhibit sufficient tribological properties in terms of plaque retention and wear when compared to those with glazed surfaces value (61, 62).

Another parameter affecting TP is thermal cycling, and it has been determined that this process reduces TP values (17). This interaction is explained by the fact that the thermal cycle changes the optical properties of the material, increases the crystal size of the material, and changes the orientation of the crystals and the glass matrix (17, 58, 63-65). In this study, although higher TP values were obtained in the ZLS groups (group CD, 17.68 (14.82-19.87); group VS, 19.58 (12.42- 23.14)) than in group EC (15.48 (12.25-19.1) as a result of aging with thermal cycling, no statistically significant difference was found in TP values before and after thermal cycling for all groups (Table 5). The current study gives similar results to previous studies in the literature focusing on the TP values of LS and ZLS samples, but it differs partially from the study of Porojan et al. (11, 17, 38, 53, 66). In the mentioned study, it was reported that LS samples had higher TP than ZLS samples, but the difference was not statistically significant (17). This difference can be due to the type and preparation of the materials used in the relevant study; only CAD/CAM materials were evaluated in the current study. In this study, it was also observed that the group VS had higher TP values than the group CD. It is thought that the difference between these groups with similar microstructure is due to the difference in crystal size. While group VS contains lithium metasilicate crystals of approximately 0.5 μm in size, group CD contains crystals of 1.0 μm in size (10).

The surface texture of dental materials affects their optical properties and TP (67, 68). For the Ra value used to measure surface roughness, 0.20 μm has been determined as the critical threshold value for bacterial retention, and it has been reported that discoloration is observed in restorations with average Ra values more than 0.20 μm and has a negative effect on plaque accumulation on teeth TP (69). In the current study, the highest Ra values were obtained from the Listerine Lemon&Salt (0.25 (0.2-0.3)) and Meridol (0.25 (0.2- 0.3)) mouthwash groups, while results similar to these values were observed in the Listerine Cool Mint (0.24 (0.2- 0.3)) mouthwash (Table 7). The group with the lowest Ra values was the control group, and it showed similar results to the study in which feldspathic ceramic, polymer-infiltrated ceramic, and lithium disilicate glass-ceramic samples were examined and it was found that Listerine lemon/salt mouthwash increased the roughness (47). This can be attributed to the chemical composition

of the mouthwash, as it has been reported that mouthwashes containing essential oils and alcohol cause higher surface roughness (70). Although the results of the present study are compatible with the data of a limited number of studies in the literature, they are not sufficient for clinical decision-making, needing future studies to confirm the data.

The surface properties of dental ceramics depend on the pH value of the solutions to which the material is exposed, and it has been determined that low pH values are effective in surface roughness (39). The mouthwashes and pH values used in the study are as follows: Meridol (pH: 3.88), Listerine Cool Mint (pH: 3.93), Klorhex (pH: 5.1-5.8), Listerine Lemon&Salt (pH: 6.56), and Curasept (pH: 5.7) (47). When these pH values are examined, the data of Cool Mint and Meridol mouthwashes are compatible with the Ra values obtained, while the fact that Lemon&Salt causes high Ra even though it has a higher pH value than these two mouthwashes. This difference is considered an interesting result of the present study and reveals the need for further studies.

According to the results of the current study, the type of ceramic material was effective on surface roughness, and LS (group EC: 0.25 (0.2-0.3)) samples had higher Ra values compared to ZLS samples (group CD: 0.22 (0.2-0.3), group VS: 0.22 (0.2- 0.3)) after immersing mouthwash solutions (Table 7). The results of this study were consistent with a recent study that evaluated full and semi-stabilized zirconia, LS, ZLS, and hybrid ceramic materials and reported that the surface roughness in LS and hybrid ceramic samples was higher than in other material groups (71). One of the reasons for explaining the difference between these materials may be the difference in the 'crystal and glass phase ratio' in the structure of the materials. Another point worth noting is that these ceramics, which contain crystalline and glass phases, have a difference in the dissolution rates between phases, and the lithium metasilicate (Li_2SiO_3) in the LS content dissolves more slowly than the glass matrix content. This causes roughness on the material surface due to clinical use (72).

One of the limitations of this study was the lack of reproduction of the oral environment, as results may vary due to individual variations. Additional limitations of the present study that need to be investigated in the next studies are not including samples of different thicknesses, exposing the samples only to mouthwash and removing the effect of saliva, not taking cement color and thickness into account in measurements, not preparing the samples in crown shape, and applying only one type of aging process to samples (thermal cycling). Therefore, future studies are needed to confirm the findings of this study and should also investigate the long-term effect of the use of mouthwash solutions, which may contribute to a clear decision for the study.

Conclusion

Based on the findings of the present study, the following conclusions were drawn:

1. There was a significant difference between the average ΔE_{00} values according to the ceramic type, and the highest discoloration was observed in the group EC.
2. Average ΔE_{00} values varied depending on the applied mouthwash solutions, and the discoloration order was; Listerine Cool Mint = Listerine Lemon & Salt > Meridol > Klorhex > Curasept > Distilled water. All discoloration values were clinically acceptable.
3. In all groups included in the study, regardless of the material, thermal cycling caused more discoloration than exposure to mouthwash.
4. While the main effect of the mouthwash solution on TP values was not found to be statistically significant, the material effect was found to be significant. The lowest TP was measured in the group EC.
5. Roughness values of all ceramic groups increased significantly after the mouthwash process, and the highest Ra was obtained after group EC was immersed in Listerine Lemon&Salt and Cool Mint mouthwashes.

Disclosures

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - M.B.; Design - M.B., M.Y.Ç.; Supervision - M.Y.Ç., B.E.G.; Materials - M.B., M.Y.Ç., B.E.G.; Data collection &/or processing - M.Y.Ç., B.E.G.; Analysis and/or interpretation - M.B., M.Y.Ç., B.E.G.; Literature search - M.B., B.E.G.; Writing - M.B.; Critical review - M.Y.Ç., B.E.G.

Conflict of Interest: There is no any conflict of interest.

Funding: There is no any funding.

References

1. Preis V, Hahnel S, Behr M, Bein L, Rosentritt M. In-vitro fatigue and fracture testing of CAD/CAM materials in implant-supported molar crowns. *Dent Mater* 2017;4:427-433. <https://doi.org/10.1016/j.dental.2017.01.003>
2. Kim HK, Kim SH. Effect of the number of coloring liquid applications on the optical properties of monolithic zirconia. *Dent Mater* 2014;30:229-237. <https://doi.org/10.1016/j.dental.2014.04.008>

3. Awad D, Stawarczyk B, Liebermann A, Ilie N. Translucency of esthetic dental restorative CAD/CAM materials and composite resins with respect to thickness and surface roughness. *J Prosthet Dent* 2015;113:534-540. <https://doi.org/10.1016/j.prosdent.2014.12.003>
4. Villarroel M, Fahl N, De Sousa AM, De Oliveira OB Jr. Direct esthetic restorations based on translucency and opacity of composite resins. *J Esthet Restor Dent* 2011;23:73-87. <https://doi.org/10.1111/j.1708-8240.2010.00392.x>
5. Colombo M, Cavallo M, Miegge M, Dagna A, Beltrami R, Chiesa M, Poggio C. Color stability of CAD/CAM Zirconia ceramics following exposure to acidic and staining drinks. *J Clin Exp Dent* 2017;9(11):e1297-e1303. <https://doi.org/10.4317/jced.54404>
6. El-Mowafy O, El-Aawar N, El-Mowafy N. Porcelain veneers: An update. *Dent Med Probl* 2018;55(2):207-211. <https://doi.org/10.17219/dmp/90729>
7. Rinke S, Rödiger M, Ziebolz D, Schmidt AK. Fabrication of Zirconia-Reinforced Lithium Silicate Ceramic Restorations Using a Complete Digital Workflow. *Case Rep Dent* 2015; 2015:162178. <https://doi.org/10.1155/2015/162178>
8. Al-Thagafi R, Al-Zordk W, Saker S. Influence of Surface Conditioning Protocols on Reparability of CAD/CAM Zirconia-reinforced Lithium Silicate Ceramic. *J Adhes Dent* 2016; 18(2):135-141. <https://doi.org/10.3290/j.jad.a35909>
9. Traini T, Sinjari B, Pascetta R, Serafini N, Perfetti G, Trisi P, Caputi S. The zirconia-reinforced lithium silicate ceramic: lights and shadows of a new material. *Dent Mater J* 2016; 35(5):748-755. <https://doi.org/10.4012/dmj.2016-041>
10. Belli R, Wendler M, de Ligny D, Cicconi MR, Petschelt A, Peterlik H, Lohbauer U. Chairside CAD/CAM materials. Part 1: Measurement of elastic constants and microstructural characterization. *Dent Mater* 2017;33(1):84-98. <https://doi.org/10.1016/j.dental.2016.10.009>
11. Demirel M, Diken Türksayar AA, Donmez MB. Translucency, color stability, and biaxial flexural strength of advanced lithium disilicate ceramic after coffee thermocycling. *J Esthet Restor Dent* 2023;35(2):390-396. <https://doi.org/10.1111/jerd.12960>
12. Riquieri H, Monteiro JB, Viegas DC, Campos TMB, de Melo RM, de Siqueira Ferreira Anzaloni Saavedra G. Impact of crystallization firing process on the microstructure and flexural strength of zirconia-reinforced lithium silicate glass-ceramics. *Dent Mater* 2018;34(10):1483-1491. <https://doi.org/10.1016/j.dental.2018.06.010>
13. 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. <https://doi.org/10.1016/j.jdent.2021.103661>
14. Aboushelib MN, Sleem D. Microtensile bond strength of lithium disilicate ceramics to resin adhesives. *J Adhes Dent* 2014;16(6):547-552. <https://doi.org/10.3290/j.jad.a33249>
15. Schwindling FS, Rues S, Schmitter M. Fracture resistance of glazed, full-contour ZLS incisor crowns. *J Prosthodont Res* 2017;61(3):344-349. <https://doi.org/10.1016/j.jpor.2016.12.008>
16. Elsaka SE, Elnaghy AM. Mechanical properties of zirconia reinforced lithium silicate glass-ceramic. *Dent Mater* 2016; 32(7):908-914. <https://doi.org/10.1016/j.dental.2016.03.013>
17. Porojan L, Vasiliu RD, Birdeanu MI, Porojan SD. Surface Characterization and Optical Properties of Reinforced Dental Glass-Ceramics Related to Artificial Aging. *Molecules* 2020; 25(15):3407. <https://doi.org/10.3390/molecules25153407>
18. Kanat-Ertürk B. Color Stability of CAD/CAM Ceramics Prepared with Different Surface Finishing Procedures. *J Prosthodont* 2020;29(2):166-172. <https://doi.org/10.1111/jopr.13019>
19. Ozen F, Demirkol N, Parlar Oz O. Effect of surface finishing treatments on the color stability of CAD/CAM materials. *J Adv Prosthodont* 2020;12(3):150-156. <https://doi.org/10.4047/jap.2020.12.3.150>
20. 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):71-75. <https://doi.org/10.1016/j.prosdent.2015.06.014>
21. Samra AP, Pereira SK, Delgado LC, Borges CP. Color stability evaluation of aesthetic restorative materials. *Braz Oral Res* 2008;22(3):205-210. <https://doi.org/10.1590/S1806-83242008000300003>
22. Sasany R, Ergun-Kunt G, Yilmaz B. Effect of mouth rinses on optical properties of CAD-CAM materials used for laminate veneers and crowns. *J Esthet Restor Dent* 2021; 33(4):648-653. <https://doi.org/10.1111/jerd.12720>
23. Turgut S, Bagis B. Colour stability of laminate veneers: an in vitro study. *J Dent* 2011;39 Suppl 3:e57-64. <https://doi.org/10.1016/j.jdent.2011.11.006>
24. Kürklü D, Azer SS, Yilmaz B, Johnston WM. Porcelain thickness and cement shade effects on the colour and translucency of porcelain veneering materials. *J Dent* 2013; 41(11):1043-1050. <https://doi.org/10.1016/j.jdent.2013.08.017>
25. Gunal B, Ulusoy MM. Optical properties of contemporary monolithic CAD-CAM restorative materials at different thicknesses. *J Esthet Restor Dent* 2018;30(5):434-441. <https://doi.org/10.1111/jerd.12382>
26. Lee YK, Lim BS, Kim CW. Effect of surface conditions on the color of dental resin composites. *J Biomed Mater Res* 2002; 63(5):657-663. <https://doi.org/10.1002/jbm.10383>
27. Alp G, Subaşı MG. Effect of surface finishing methods and aging on surface roughness and optical properties of zirconia-reinforced lithium silicate glass-ceramic. *Cumhuriyet Dental Journal* 2019;22(1):121-130. <https://doi.org/10.7126/cumudj.502650>
28. Atala MH, Yeğin E, Atala N, Senlen E, Bağlar S. Effects of mouthrinses on discoloration of CAD-CAM manufactured restorative materials. *Am J Dent* 2019; 32(6):293-298.
29. Fischman SL. A clinician's perspective on antimicrobial mouthrinses. *J Am Dent Assoc* 1994;125 Suppl 2:20S-22S. [https://doi.org/10.1016/S0002-8177\(94\)14003-3](https://doi.org/10.1016/S0002-8177(94)14003-3)
30. Moran J, Addy M, Kohut B, Hovliaras CA, Newcombe RG. Efficacy of mouthrinses in inhibiting the development of supragingival plaque over a 4-day period of no oral hygiene. *J Periodontol* 1994;65(10):904-907. <https://doi.org/10.1902/jop.1994.65.10.904>
31. Luo MR, Cui G, Rigg B. The development of the CIE 2000 colour difference formula: CIEDE2000. *Color Res Appl* 2001; 26:340-350. <https://doi.org/10.1002/col.1049>
32. Paravina RD, Ghinea R, Herrera LJ, Bona AD, Igiel C, Linninger M, Sakai M, Takahashi H, Tashkandi E, Perez Mdel M. Color difference thresholds in dentistry. *J Esthet Restor Dent* 2015;27 S1:S1-9. <https://doi.org/10.1111/jerd.12149>
33. Garza LA, Thompson G, Cho SH, Berzins DW. Effect of toothbrushing on shade and surface roughness of extrinsically stained pressable ceramics. *J Prosthet Dent* 2016; 115(4):489-494. <https://doi.org/10.1016/j.prosdent.2015.09.013>
34. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. *J Dent* 1999;27 (2):89-99. [https://doi.org/10.1016/S0300-5712\(98\)00037-2](https://doi.org/10.1016/S0300-5712(98)00037-2)
35. Yalcin F, Gürgan S. Effect of two different bleaching regimens on the gloss of tooth colored restorative materials. *Dent Mater* 2005; 21(5):464-468. <https://doi.org/10.1016/j.dental.2004.07.011>
36. Conrad HJ, Seong WJ, Pesun IJ. Current ceramic materials and systems with clinical recommendations: a systematic review. *J Prosthet Dent* 2007;98(5):389-404. [https://doi.org/10.1016/S0022-3913\(07\)60124-3](https://doi.org/10.1016/S0022-3913(07)60124-3)
37. 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):71-75. <https://doi.org/10.1016/j.prosdent.2015.06.014>
38. Alp G, Subaşı MG, Johnston WM, Yilmaz B. Effect of surface treatments and coffee thermocycling on the color and translucency of CAD-CAM monolithic glass-ceramic. *J Prosthet Dent* 2018;120(2):263-268. <https://doi.org/10.1016/j.prosdent.2017.10.024>
39. 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):430-436. <https://doi.org/10.1016/j.prosdent.2016.10.023>

40. Soygun K, Varol O, Ozer A, Bolayir G. Investigations on the effects of mouthrinses on the colour stability and surface roughness of different dental bioceramics. *J Adv Prosthodont* 2017;9(3):200-207. <https://doi.org/10.4047/jap.2017.9.3.200>
41. Alpkilic DS, Ongul D, Isler Deger S. Stainability of different ceramic materials against mouth rinses and effect of polishing after staining. *J Prosthet Dent* 2021;126(5):686.e1-686.e7. <https://doi.org/10.1016/j.prosdent.2021.06.002>
42. Dumitrescu, Alexandrina L. Antibiotics and antiseptics in periodontal therapy. Berlin, Germany: Springer, 2011. <https://doi.org/10.1007/978-3-642-13211-7>
43. Cevik P, Zor ZF. Antibakteriyel gargara kullanımına bağlı diş renklenmesinin farklı beyazlatma teknikleri ile giderilmesi. *Selcuk Dental Journal* 2018;5(3):218-224. <https://doi.org/10.15311/selcukdentj.311303>
44. Gürkan S, Onen A, Köprülü H. In vitro effects of alcohol-containing and alcohol-free mouthrinses on microhardness of some restorative materials. *J Oral Rehabil* 1997; 24(3):244-246. <https://doi.org/10.1111/j.1365-2842.1997.tb00321.x>
45. Ghavam M, Amani-Tehran M, Saffarpour M. Effect of accelerated aging on the color and opacity of resin cements. *Oper Dent* 2010;35(6):605-9. <https://doi.org/10.2341/09-161-L>
46. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. *J Dent* 1999; 27(2):89-99. [https://doi.org/10.1016/S0300-5712\(98\)00037-2](https://doi.org/10.1016/S0300-5712(98)00037-2)
47. Lee JH, Kim SH, Yoon HI, Yeo IL, Han JS. Colour stability and surface properties of high-translucency restorative materials for digital dentistry after simulated oral rinsing. *Eur J Oral Sci* 2020;128(2):170-180. <https://doi.org/10.1111/eos.12676>
48. Leal JP, da Silva JD, Leal RFM, Oliveira-Júnior CDC, Prado VLG, Vale GC. Effect of Mouthwashes on Solubility and Sorption of Restorative Composites. *Int J Dent* 2017; 2017:5865691. <https://doi.org/10.1155/2017/5865691>
49. Ozdogan A, Duymus ZY, Ozbayram O, Bilgic R. Effect of different bleaching agents on the surface roughness and color stability of feldspathic porcelain. *Braz Dent Sci* 2019;22(2): 213-219. <https://doi.org/10.14295/bds.2019.v22i2.1695>
50. Pires-de-Souza FC, Contente MM, Alandia-Román CC, Vicente SA, Tonani R. Effect of bleaching agent and topical fluoride application on color and gloss of dental ceramics. *Gen Dent* 2016;64(6):e16-e20.
51. Ural C, Gencer Y, Tarakcı M, Aşşan MA, Arıcı S, Tatar N. Effect of bleaching agents on surface texture of feldspathic ceramic. *J Exper and Clin Med* 2014;31(3):177-181. <https://doi.org/10.17098/amj.84924>
52. Ertürk-Avunduk AT, Aksu S, Delikan E. The effects of mouthwashes on the color stability of resin-based restorative materials. *Odovtos-Int. J of Dent. Sci.* 2021;23(1):91-102.
53. Arif R, Yilmaz B, Johnston WM. In vitro color stainability and relative translucency of CAD-CAM restorative materials used for laminate veneers and complete crowns. *J Prosthet Dent* 2019;22(2):160-166. <https://doi.org/10.1016/j.prosdent.2018.09.011>
54. Wang F, Takahashi H, Iwasaki N. Translucency of dental ceramics with different thicknesses. *J Prosthet Dent* 2013; 110(1):14-20. [https://doi.org/10.1016/S0022-3913\(13\)60333-9](https://doi.org/10.1016/S0022-3913(13)60333-9)
55. Alayad AS, Alqhatani A, Alkathheeri MS, Alshehri M, AlQahtani MA, Osseil AEB, Almusallam RA. Effects of CAD/CAM ceramics and thicknesses on translucency and color masking of substrates. *Saudi Dent J* 2021;33(7):761-768. <https://doi.org/10.1016/j.sdentj.2020.03.011>
56. Caprak YO, Turkoglu P, Akgungor G. Does the Translucency of Novel Monolithic CAD/CAM Materials Affect Resin Cement Polymerization with Different Curing Modes? *J Prosthodont* 2019;28(2):e572-e579. <https://doi.org/10.1111/jopr.12956>
57. Ilie N, Hickel R. Correlation between ceramics translucency and polymerization efficiency through ceramics. *Dent Mater* 2008;24(7):908-914. <https://doi.org/10.1016/j.dental.2007.11.006>
58. Elsaka SE, Elnaghy AM. Mechanical properties of zirconia reinforced lithium silicate glass-ceramic. *Dent Mater* 2016; 32(7):908-914. <https://doi.org/10.1016/j.dental.2016.03.013>
59. Kang SH, Chang J, Son HH. Flexural strength and microstructure of two lithium disilicate glass ceramics for CAD/CAM restoration in the dental clinic. *Restor Dent Endod* 2013;38(3):134-40. <https://doi.org/10.5395/rde.2013.38.3.134>
60. Kanchanasavita W, Triwatanana P, Suputtamongkol K, Thanapitak A, Chatchaiganan M. Contrast ratio of six zirconia-based dental ceramics. *J Prosthodont* 2014; 23(6):456-461. <https://doi.org/10.1111/jopr.12143>
61. Dal Piva A, Contreras L, Ribeiro FC, Anami LC, Camargo S, Jorge A, Bottino MA. Monolithic Ceramics: Effect of Finishing Techniques on Surface Properties, Bacterial Adhesion and Cell Viability. *Oper Dent* 2018;43(3):315-325. <https://doi.org/10.2341/17-011-L>
62. Lee A, Swain M, He L, Lyons K. Wear behavior of human enamel against lithium disilicate glass ceramic and type III gold. *J Prosthet Dent* 2014;112(6):1399-1405. <https://doi.org/10.1016/j.prosdent.2014.08.002>
63. Hallmann L, Ulmer P, Lehmann F, Wille S, Polonskyi O, Johannes M, Köbel S, Trottenberg T, Bornholdt S, Haase F, Kersten H, Kern M. Effect of surface modifications on the bond strength of zirconia ceramic with resin cement resin. *Dent Mater* 2016; 32(5):631-639. <https://doi.org/10.1016/j.dental.2016.02.001>
64. Harianawala HH, Kheur MG, Apte SK, Kale BB, Sethi TS, Kheur SM. Comparative analysis of transmittance for different types of commercially available zirconia and lithium disilicate materials. *J Adv Prosthodont* 2014;6(6):4564-61. <https://doi.org/10.4047/jap.2014.6.6.456>
65. Paravina RD, Ontiveros JC, Powers JM. Curing-dependent changes in color and translucency parameter of composite bleach shades. *J Esthet Restor Dent* 2002;14(3):158-166. <https://doi.org/10.1111/j.1708-8240.2002.tb00516.x>
66. Subaşı MG, Alp G, Johnston WM, Yilmaz B. Effect of thickness on optical properties of monolithic CAD-CAM ceramics. *J Dent* 2018;71:38-42. <https://doi.org/10.1016/j.jdent.2018.01.010>
67. Guler AU, Duran I, Co A, Ozkan P. Effects of air polishing powders on the surface roughness of composite resins. *Journal of dental sciences* 2010;5(3):136-143. [https://doi.org/10.1016/S1991-7902\(10\)60020-7](https://doi.org/10.1016/S1991-7902(10)60020-7)
68. Tong H, Tanaka CB, Kaizer MR, Zhang Y. Characterization of three commercial Y-TZP ceramics produced for their high-translucency, high-strength and high-surface area. *Ceram Int* 2016;42(1 Pt B):1077-1085. <https://doi.org/10.1016/j.ceramint.2015.09.033>
69. Bollen CM, Lambrechts P, Quirynen M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: a review of the literature. *Dent Mater* 1997;13(4):258-269. [https://doi.org/10.1016/S0109-5641\(97\)80038-3](https://doi.org/10.1016/S0109-5641(97)80038-3)
70. Gehlot PM, Sudeep P, Manjunath V, Annapoorna BM, Prasada LK, Nandlal B. Influence of various desensitizing mouthrinses and simulated toothbrushing on surface roughness and microhardness of tetric N-Ceram bulk-fill resin composite: An in vitro study and scanning electron microscope analysis. *Eur J Dent* 2022;16(4):820-827. <https://doi.org/10.1055/s-0041-1739547>
71. Kenawy ER. Effect of simulated gastric acid on surface roughness of different types of dental ceramics. *Egypt Dent J (Fixed Prosthodontics, Removable Prosthodontics and Dental Materials)* 2021;67(1):711-716. <https://doi.org/10.21608/edj.2020.49879.1339>
72. Kilinc H, Turgut S. Optical behaviors of esthetic CAD-CAM restorations after different surface finishing and polishing procedures and UV aging: An in vitro study. *J Prosthet Dent* 2018;120(1):107-113. <https://doi.org/10.1016/j.prosdent.2017.09.019>