ORIGINAL RESEARCH

Influence of Arabic Qahwa Beverage on Optical and Mechanical Properties of Lithium Disilicate Glass Ceramics and Zirconia Restorative Materials

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Abstract

Aims: The study aims to assess the effect of Arabic Qahwa (AQ) on the color parameters of lithium disilicate glass ceramic (LDGC), IPS e.max computer-aided design (CAD), and multilayered zirconia CAD/ computer-aided manufacturing (CAM) ceramic materials after immersion in AQ and also, to measure the biaxial fracture strength and fracture modes of the tested materials.

Methods: Sixty circular specimens were milled from LDGC and zirconia. Before AQ immersion, the color parameters of the specimens L, a, and b were measured and recorded using a spectrophotometer on white, black, and gray background and analyzed after AQ staining and aging for 14 days. Biaxial compressive forces and fracture types were recorded. The collected data were analyzed with SPSS for descriptive statistics, one-way analysis of variance, and *post hoc* tests.

Results: The overall TP values were 16.79 and 15.85 for LDGC and zirconia, respectively. The recorded ΔE^* values were 2.63 and 2.99 for LDGC and zirconia, which have no remarkable difference. The TP values after AQ staining were slightly lesser. Subgroup analysis revealed considerable differences in TP values among zirconia specimens under both backgrounds, whereas substantial differences in ΔE^* values were observed between LDGC and zirconia under white background only. LDGC had higher biaxial fracture forces than zirconia. Reparable, semi-reparable, and non-reparable fractures comprised 60, 30, and 10% of the overall fracture modes, respectively, with significant differences between and within groups ($p = 0.034$).

Conclusion: AQ staining had a marked effect on the TP and ΔE^* values of the tested CAD/CAM materials, but the values were within clinically acceptable levels. The optical properties were dependent on the material. LDGC had higher biaxial fracture forces than zirconia. Reparable fracture was the dominant type among the examined materials.

Clinical significance: Glazed surface for any CAD/CAM ceramic prostheses is highly recommended. Both tested materials are strongly recommended to be used for AQ consumers.

Keywords: Arabic Qahwa, Biaxial fracture, Color changes, Color measurements, Lithium disilicate, Translucency parameter, Zirconia.

The Journal of Contemporary Dental Practice (2021): 10.5005/jp-journals-10024-3244

Introduction

Remarkable progress in dental prosthetic materials and knowledge, such as computer-aided design (CAD)/computer-aided manufacturing (CAM), has made dental restoration aesthetic, inexpensive, efficient, and predictable.[1] Those systems are increasingly used in dentistry, they allow a completely digital workflow from impression to the final framework, and the materials used show excellent mechanical properties and biocompatibility,[1,2] as well as respectable precision.[3] Prosthetic materials are predesigned as a block to be milled into prostheses. These ceramic blocks are pre-sintered. After they are milled, the blocks are fully centered at the standardized pressure and temperature to achieve the desired mechanical, optical, and biological properties.[4,5]

Lithium disilicate glass ceramic (LDGC) prosthetic materials dominate the arena of dentistry because of their ability to reproduce natural teeth with long-term survival rate and success. LDGC is frequently promoted as IPS e.max CAD and is composed of a crystalline phase (70%) and a glassy matrix. Coloring ions are dispersed in the matrix and determine the color of the material after crystallization. They have three different translucency levels: high, medium, and low translucency. Different translucency levels are obtained by varying the crystal size, in which increasing the size of the crystals causes an increase in translucency.[6–8] Cubic zirconia is considered a potential competitor and has very similar indications as lithium disilicate. A single zirconia crystal contains three phases (tetragonal, monoclinic, and cubic) and is stabilized using metal oxides in the desired phase.[9–12] According to its microstructural content, zirconia could be classified into fully stabilized, partially stabilized, and tetragonal zirconia polycrystals,[12] which have different coloring techniques.

The optical properties of porcelains take the spotlight when topics are considered for research. A ΔE^* value of less than 3.7 is imperceivable in the oral atmosphere.[13,14] Douglas et al.[15] stated that ΔE^* values below 3 are considered clinically

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How to cite this article: Alahmari NM. Influence of Arabic Qahwa Beverage on Optical and Mechanical Properties of Lithium Disilicate Glass Ceramics and Zirconia Restorative Materials. J Contemp Dent Pract 2021;x(x):xx–xx.

Source of support: Nil

Conflict of interest: None

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imperceptible, ΔE^* values between 3 and 5 are considered clinically acceptable, ΔE^* values above 5 are not acceptable, and restorations with color change should be remade. According to the Internal Commission on Illumination (CIL), the color coordinates are *L*, *a*, and *b* (*L* stands for the degree of lightness, *a* is the degree of redness/greenness, and *b* is the degree of yellowness/blueness).[16] Color coordinates are obtained and substituted into equations to calculate ΔE^*.[17] The translucency of dental ceramic is the amount of light passing through a material. Translucency has a close relationship with the microstructure; chemical nature; number of crystals; the size of particles and pores; sintered density; and the amounts of absorbed, reflected, and transmitted light.[18–21]

Coffee is the most popular consumed beverage worldwide. Among the Saudi population, a special type of coffee called "Arabic Qahwa (AQ)" is consumed. AQ contains additives, such as saffron, ginger, and cardamom. However, AQ causes discoloration because of its additive constituents, which results in the staining of aesthetic prostheses during intraoral survival.[13,22] Recent studies evaluated materials for aesthetic restorations. However, few focused on the recent advances of CAD/CAM materials for aesthetic restorations among AQ consumers. This laboratory work aimed to assess the effect of AQ on the color parameters, such as translucency parameter (TP) and mean color change (ΔE^*), of LDGC (IPS e.max CAD) and multilayer zirconia (Ceramill Zolid PS) CAD/CAM ceramic materials after immersion in AQ for 14 days and to measure the biaxial fracture strength and the type of fracture modes of the tested materials. The null hypotheses are as follows: (1) changes in TP and ΔE^* values before and after AQ staining and artificial aging have no significant differences, and (2) the values of biaxial fracture forces or the fracture type of the tested CAD/CAM restorative materials have no significant differences.

Materials and Methods

Study Design and Sample Size

This study was conducted in King Khalid University, College of Dentistry, Abha, Saudi Arabia in May 2021. The effects of AQ on the optical properties, biaxial fracture forces, and fractures modes of CAD/CAM ceramic materials were tested.

Specimen Fabrication and Surface Treatments

Sixty circular specimens were manufactured using the CAD/CAM system from LDGC (IPS e.max CAD) and multilayer zirconia (Ceramill Zolid PS) CAD/CAM ceramic block materials (Vita Zahnfabrik), with 30 samples from each material. The disks had 12 mm diameter and 2.0 ± 0.2 mm thickness. The thicknesses of the specimens were measured using a digital caliper. For the LDGC group, a glaze layer (IPS e.max Ceram Glaze paste, Ivoclar Vivadent, Schaan AG, Liechtenstein) was applied to all specimens on the experimental side before the final heat treatment in the furnace for complete crystallization. For the zirconia group, the specimens were sintered and glazed in a furnace for 2 hours at 1550°C. Each group was divided into three subgroups according to background surfaces (white, black, gray) with 10 samples for each subgroup.

Translucency and Mean Color Change Measurements

After specimens in the six subgroups were numbered, a spectrophotometer device with a 6-mm-diameter tip (VITA Easyshade Advance Compact, Vita Zahnfabrik, Bad Säckingen, Germany) was standard before individual assessment. International commission on Illumination (CIE) L^*, a^*, and b^* values were documented for each sample using the device.

For TP color assessments, each specimen color parameters measurements were recorded at three different points on white and black backgrounds, and then the average values were recorded of each tested material. A square window opening (2×2 cm^2) was used and fixed on the two backgrounds (white and black) to ensure that the specimen was in the same area during TP reading. TP measurements were obtained by calculating the color difference in the specimen over white and black backgrounds using the formula: $TP = [(L_W - L_B)^2 + (a_B - a_W)^2 + (b_B - b_W)^2]^{1/2}$, where subscripts W and B refer to the color coordinates over white and black backgrounds, respectively. A TP of 0 corresponds to full opacity, whereas a high TP indicates high translucency.[20,23,24]

For mean color changes (ΔE^*), all samples were measured thrice under gray background to obtain their CIE *L*, *a*, and *b* values and the average value was considered.[13,14] The *L1*, *a1*, and *b1* values of all the samples under gray backgrounds were recorded as the average color changes before AQ immersion.

Arabic Qahwa Staining and Aging

The samples were immersed for 14 days in AQ (Baja Food Industrial Co., Jeddah, Saudi Arabia). The AQ used in this study is commercially available and came in a nitrogen-flushed package for single use. The staining AQ solution prepared from each packet (30 g) was mixed with 0.5 L of boiled water (100°C) and kept boiling for 15 seconds according to the manufacturer's instructions (0.6 g for each 1 mL). Two packets with 30 g each were used for all samples every day, the AQ was changed every 12 hours.[13]

The color parameters measured after AQ staining and aging are denoted as *L*2, *a*2, and *b*2. These parameters were assessed under the matching background, location, operator, and the differences among second and first values were considered as the mean values. The values were used in the calculation for color parameter measurements. ΔE^* values were calculated using the equation: $\Delta E^* = [(L1^* - L2^*)^2 + (a1^* - a2^*)^2 + (b1^* - b2^*)^2]^2/2$.

Surface Roughness Measurements

Surface roughness test was performed after recording the TP and ΔE^* values. A simulation was performed by 3D non-contact surface metrology and interferometry (Bruker Contour GTK, Bruker Nano Surfaces Division, Tucson, Arizona, USA) in the material laboratory of King Saud University. Specimens were measured by vertical scan interferometry using a 5× Michelson magnification lens with a field of view of 1.5×1.5 mm^2, a Gaussian regression filter, a scan speed of 1×, and a threshold of 4. Specimens were secured on the profilometer machine and adjusted manually to record the replica on the monitor screen. The microscope has Vision 64 (Bruker) software, which controls the device location, performs data analyses, and produces a graphical output. Four specimens were selected from each subgroup and then scanned at two supposed points. The measurements were averaged accordingly to determine the average surface roughness (Ra) in micrometers. Each sample was scanned three times, and the results were averaged accordingly to determine the Ra value. Ra measurements were performed following the ISO 11562 recommendations for standardization.[25,26]

Biaxial Compressive Force Test

Biaxial compressive force test is a common in vitro test used to estimate the strength of dental prosthetic CAD/CAM materials. The piston-on-three-ball test was used to measure biaxial flexural strength. Disk specimens were centered and supported on three symmetrically spaced steel balls (3.4 mm diameter). The diameters of the piston tip and the support circle were 1.2 and 12.0 mm, separately (Fig. 1). The forces were fixated to the midpoint of the specimen via a flat tip with 1.4 mm radius of the piston and at a crossheading of 1.0 mm/minute as proposed in ISO 6872 and applied in the air at room temperature by means of a universal mechanical testing machine. A 50 µm thickness thin plastic film was fixed on the outer or exposed surfaces of the specimens for the piston to dispense the forces homogeneously. Fracture load forces were documented in Newtons. The mean of the biaxial forces of each ceramic type was calculated, and the results between the tested materials and different backgrounds were compared.[27,28]

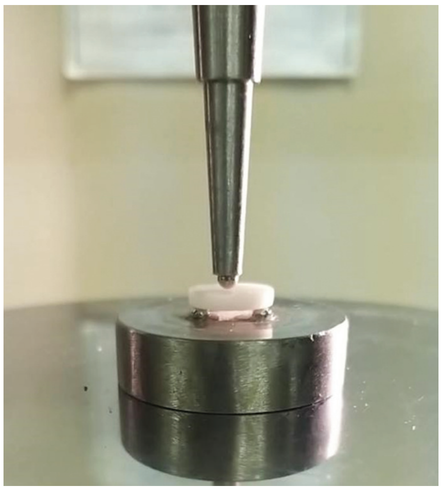


Fig. 1: Specimen setup during biaxial forces strength application

Fracture Type Recording

The fracture mode was categorized according to the principles presented in Table 1, and each sample was determined based on the number of pieces as follows: type I, the sample is broken in two halves (reparable fracture); type II, the samples is broken into 3–4 pieces (less or semi-reparable fracture); type III, the sample fractures into more than four pieces (non-reparable fracture). Flowchart 1 showed the steps and type of the material groups and subgroups as well as the tests used.

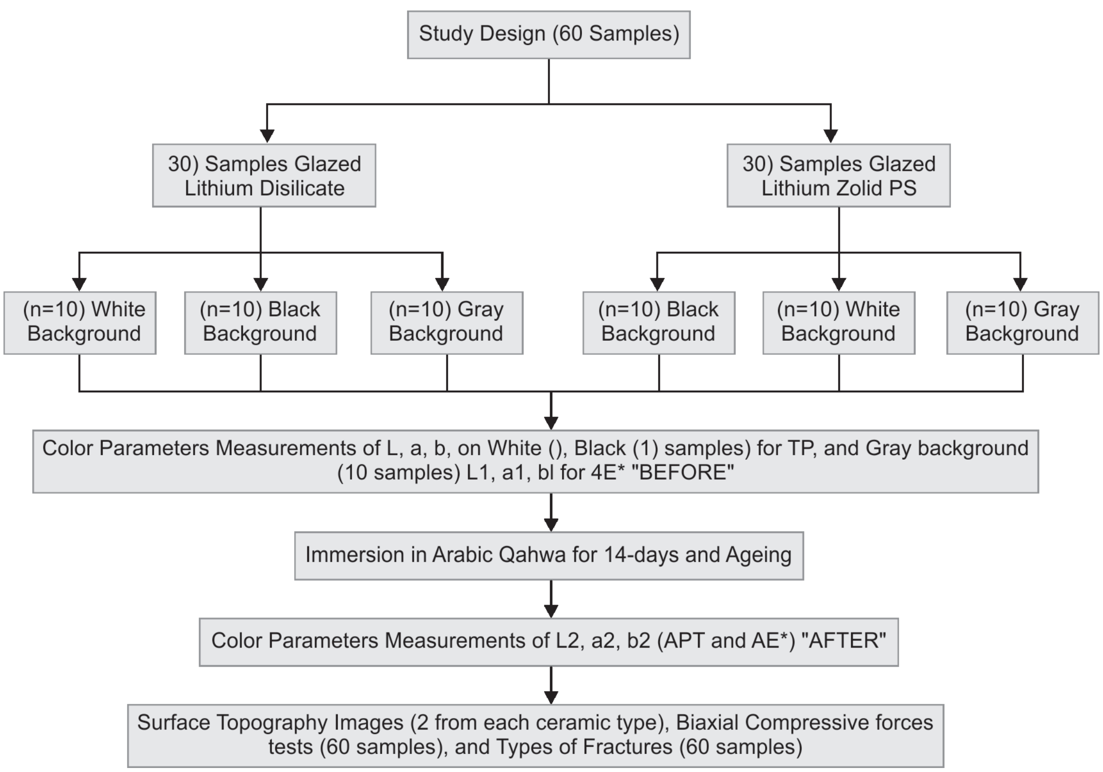
Statistical Analysis

Power analysis calculation was performed to determine the adequate sample size to obtain a statistically significant outcome. The result showed that 30 samples per group (10 samples for each subgroup) are required at a 95% confidence level, a power of 80%, and a SD of 0.4. The IBM SPSS 20.0 package program for descriptive statistics was used to calculate the mean *L**, *a**, and *b** values of the LDGC and zirconia materials in black, white, and gray backgrounds before and after AQ staining and aging. The values were presented as the means of the color data and standard deviation (SD). For repetitive measurements, one-way analysis of variance (ANOVA) was performed to compare the cases exposed

Table 1: Fracture classifications and criteria[19]

Fracture mode	*Definitions*
Type I/uniform fracture (reparable fracture)	A fracture passing at the middle and resulting in 2 pieces with equal sizes
Type II/mixed fracture (semi-reparable fracture)	A fracture resulting in 3–4 pieces
Type III/complicated fracture (non-reparable fracture)	A fracture resulting in more than 4 pieces

Flowchart 1: Flowchart representation of groups and subgroups distribution for the various tests conducted in the study



to aging in terms of TP (ΔL, Δa, and Δb) and ΔE^*. *Post hoc* test was used to compare the significance between and within groups and subgroups. The $p < 0.05$ indicated statistical significance. Moreover, biaxial fracture forces and fracture modes after AQ staining and aging were determined.

Results

No specimens were misplaced or lost during the color parameter measurements, the AQ staining and aging workflow, and the biaxial fracture force and failure type determination. The mean color parameter values of the tested CAD/CAM ceramic materials before and after AQ staining are presented in Table 2. The L^*, a^*, and b^* values of the tested CAD/CAM materials slightly increased after AQ staining for 14 days. In terms of TP, the L value increased in LDGC and decreased in zirconia after AQ immersion, whereas a and b values decreased in both materials. Nonetheless, the ΔE^* values under gray background were almost the same.

The mean and SD of TP values of the tested ceramic materials were calculated. The results showed a significant difference in the TP values among zirconia samples under different backgrounds ($p \geq 0.043$), whereas no significant differences were observed in the TP values of LDGC samples in different backgrounds. The mean and SD of the ΔE^* values of LDGC and zirconia groups under gray background recorded a value of $p = 0.064$, 0.043 (Table 3). *Post hoc* test was used to confirm and investigate the results between the subgroups of the tested materials. In Table 3, there were no significant differences in relation to mean color changes ΔE^* so it does not go for further assessments (*Post hoc*). Table 4 illustrates the significant differences between subgroups of LDGC and zirconia with different backgrounds. The Ra values and surfaces characteristics of LDGC (3.31 μm) were equal with similar profile in comparison with zirconia (3.33 μm) based on the 3D images of Ra graphical output after AQ immersion for 14 days (Figs 2A to D).

The mean and SD values of the biaxial compressive strengths of the tested ceramic materials are presented in Table 5. Significant differences were recorded between the two ceramic materials and two backgrounds with $p \geq 0.001$. The *post hoc* test results recorded a significant difference between the zirconia samples under different backgrounds, but not in LDGC samples under different backgrounds. So, no further assessments were not conducted in relation to biaxial forces. The percentages of different fracture types after biaxial force application are shown in Figure 3. Among LDGC samples, the dominant fracture type under white and black backgrounds was reparable fracture, in which the specimens were divided into two equal sizes (type I). Types I and II fracture types had similar percentages in zirconia samples, and each background showed three samples of type III fracture. Reparable, semi-reparable, and non-reparable fractures comprised 60, 30, and 10% of the overall fracture mode, respectively, and had significant differences with $p = 0.034$. The results of two- and three-way repeated-measures

Table 2: L^*, a^*, and b^* values of LDGC and zirconia before and after AQ staining and aging over black, white, and gray backgrounds

Ceramic type	*Color parameters under the white background*					
	L (baseline)	*L (14 days)*	*a (baseline)*	*a (14 days)*	*b (baseline)*	*b (14 days)*
LDGC	76.18	76.26	2.34	2.06	18.62	17.04
	Color parameters under black background					
	77.24	77.80	2.86	2.68	17.60	16.04
Zirconia	*Color parameters under white background*					
	75.14	74.28	2.68	2.02	16.88	16.42
	Color parameters under black background					
	76.44	75.94	2.56	2.04	17.24	16.86
	Color parameters under gray background					
LDGC	76.53	76.71	2.31	2.46	16.54	17.11
Zirconia	75.79	75.11	2.62	2.03	17.06	17.14

Table 3: Descriptive statistics and ANOVA of the optical properties (TP and ΔE^*) values of LDGC and zirconia before and after AQ immersion and aging

Ceramic type	*TP mean and SD before AQ immersion*	*TP mean and SD after AQ immersion*	*Overall TP*	*p value*
LDGC (White)	16.67 (0.94)	16.01 (1.11)	16.79 (0.96)	0.064
LDGC (Black)	17.37 (1.16)	16.70 (0.62)		
Zirconia (White)	16.01 (1.09)	15.53 (1.09)	15.85 (0.940	0.043*
Zirconia (Black)	16.41 (1.11)	15.49 (0.79)		
Total	16.62 (1.20)	15.93 (1.01)		
Ceramic type	*Mean and SD of color change before AQ immersion*	*Mean and SD of color change after AQ immersion*	*Overall ΔE^**	*p value*
LDGC	2.38 (0.17)	2.76 (0.35)	2.63 (0.28)	0.056
	2.55 (0.21)	3.11 (0.40)		
Zirconia	2.69 (0.53)	3.16 (0.36)	2.99 (0.45)	0.058
	2.75 (0.56)	3.25 (0.34)		
Total	2.59 (0.19)	3.07 (0.40)		

*$p > 0.050$ is significant

ANOVA (Table 6) presented significant differences between all variables except the interaction of TP with other variables, such as ceramic type, and ΔE^* with $p \geq 0.001$.

Discussion

CAD/CAM restorations contribute some degree of color instability to the oral cavity, which might be related to the quality of drinking beverage. The current laboratory works were designed to calculate the outcome of AQ immersion for 14 days on the optical properties (i.e., TP and ΔE^*) of LDGC and zirconia CAD/CAM ceramic materials. Similarly, the biaxial fracture strengths and fracture modes of the tested materials were evaluated. Spearman's test was performed to categorize the relationship of the tested CAD/CAM prosthetic materials. The results of Spearman's tests ($r = 0.63, 0.54$) demonstrated moderate positive correlation coefficients. The overall TP values were 16.79 and 15.85 for LDGC and zirconia, respectively, which were in parallel with previous studies.[19,23,24] The total ΔE^* recorded after 14 days of AQ immersion were 2.63 and 2.99, which indicated clinical acceptability. These values agreed with previous studies on the color change values of CAD/CAM ceramic materials.[4,13,19,23] The null hypotheses regarding the effect of AQ immersion on colors (TP and ΔE^*) were partially rejected because significant differences between LDGC under black background and zirconia under white and black backgrounds were observed.

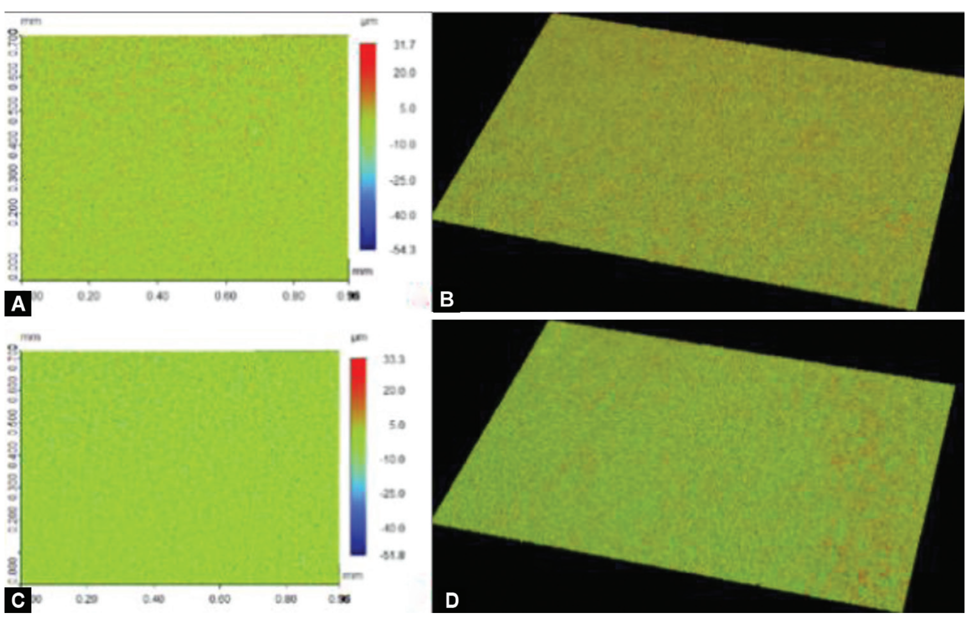
Table 4: *Post hoc* tests for the tested subgroups

	TP			
Ceramic type	*LDGC (White)*	*LDGC (Black)*	*Zirconia (White)*	*Zirconia (Black)*
LDGC (White)	—	0.212	0.056	0.050*
LDGC (Black)	0.212	—	0.003*	0.002*
Zirconia (White)	0.056	0.003*	—	0.959
Zirconia (Black)	0.050*	0.002*	0.959	—
	ΔE^*			
Ceramic type	*LDGC (White)*	*LDGC (Black)*	*Zirconia (White)*	*Zirconia (Black)*
LDGC (White)	—	0.006*	0.000*	0.000*
LDGC (Black)	0.006*	—	0.329	0.082
Zirconia (White)	0.000*	0.329	—	0.429
Zirconia (Black)	0.000*	0.082	0.429	—

*$p > 0.050$ is significant

The translucency of the prosthesis has a remarkable effect on the total aesthetic success of the prostheses, and the reproduction of color and translucency of natural teeth is one of the main goals for aesthetic dental restorations.[23] The values of TP before and after AQ staining and immersion were 16.62 and 15.93, respectively, which were slightly lesser than the values documented by Koseoglu et al.,[23] who recognized that the TP value of zirconia ceramic materials reaches 18.00 and 17.5 before and after thermocycling. Parallel and similar TP values were recorded by Al Moaleem et al.[19] Moreover, Vasiliu et al.[1] observed that the TP values of milled feldspathic and zirconia ceramics are 15 ± 1.2 and 13 ± 1.4, respectively.[24] Alshali et al., examined the TP values of different types of monolithic zirconia and registered TP values of 11.9–12.9, which were lesser than the values recorded in the present study.[29] This difference can be clarified by the thickness and shape of the tested CAD/CAM ceramic materials, because they used circular 0.5-mm-thick samples, whereas the present study used 12×2.0 mm^2 samples. Alamledin et al.[30] investigated the effect of different thicknesses on the translucency of two monolithic zirconia dental ceramics. They concluded that ceramic type and thickness have remarkable effects on the TP of monolithic zirconia. The TP values of LDGC materials with different surface treatments (hydrofluoric acid, silane bonding agent, air abrasion) were higher in comparison with the control group.[31]

An extended visual rating scale was made to interpret the values from a very slight mismatch in color with very good aesthetics to obvious variance but with usual acceptability to most patients.[32] Lesser ΔE^* values were obtained by Soares et al.,[22] who assessed LDGC samples after different surface treatments. They found



Figs 2A to D: 3D images of the Ra graphical outputs of (A) Black LDGC background; (B) White LDGC background; (C) Zirconia black background; and (D) Zirconia white background

Table 5: Mean and SD of the biaxial compressive strengths of the tested materials by ANOVA and *post hoc* test

Ceramic type	*Sample (N)*	*Background*	*Mean and SD*	*Minimum*	*Maximum*	*p value*
LDGC	10	White	843.43 (42.38)	775.94	897.11	0.052
	10	Black	836.37 (33.32)	799.46	889.06	
Zirconia	10	White	656.10 (31.11)	598.74	682.26	0.038*
	10	Black	635.82 (42.67)	589.29	682.12	
LDGC	10	Gray	830.20 (28.24)	793 .84	882.14	0.126
Zirconia	10	Gray	632. 64 (31.62)	594.24	643.28	

Post hoc tests

Ceramic type	*LDGC (White)*	*LDGC (Black)*	*Zirconia (White)*	*Zirconia (Black)*
LDGC (White)	—	0.679	0.000	0.000
LDGC (Black)	0.679	—	0.000	0.000
Zirconia (White)	0.000	0.000	—	0.240
Zirconia (Black)	0.000	0.000	0.240	—

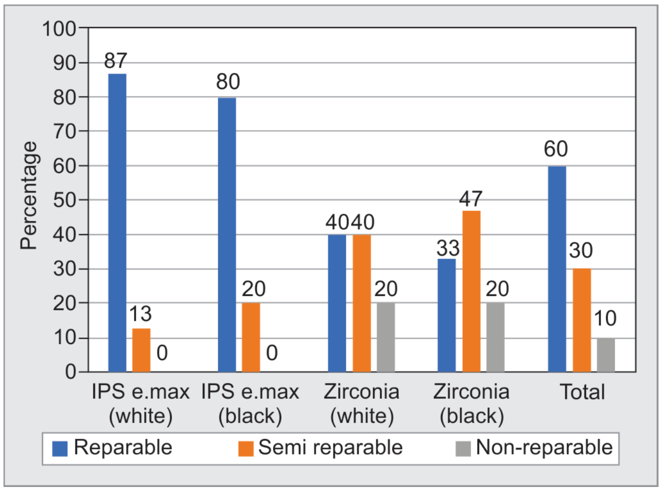


Fig. 3: Percentage of the failure mode for different ceramic types after AQ staining

Table 6: Two- and three-way repeated-measures ANOVA of ceramic type, biaxial force, TP, and ΔE^* values

Source	*Type III sum of squares*	*df*	*Mean square*	*F*	*p value*
Intercept	21186.80	1	21186.80	13951.30	0.000*
Ceramic	23.57	3	7.86	5.17	0.004*
Biaxial fracture force	9.32	1	9.32	18.83	0.000*
TP	1.883	1	1.883	3.827	0.060
ΔE^*	4.61	1	4.61	68.91	0.000*
Ceramic × biaxial fracture force	1.05	3	0.35	0.71	0.554
Ceramic × TP	0.949	2	0.474	0.964	0.393
Ceramic × ΔE^*	0.09	3	0.03	0.45	0.000*
Ceramic × Biaxial fracture force × TP	2.505	4	0.626	1.272	0.303
Ceramic × Biaxial fracture force × TP × ΔE^*	641.96	1	641.96	7511.04	0.000*
Error	54.670	36	1.52		

*Significant difference at $p \leq 0.05$

that aluminum oxide had the highest ΔE^* value (1.42), followed by hydrofluoric acid and silane coupling agents.[30] A higher ΔE^* value (5.4 ± 0.6) was recorded by Ozdemir and Surmelioglu, who evaluated the ΔE^* of zirconia CAD/CAM ceramic materials before and after 14 days of immersion in normal saline.[33] Clinically, the performance of LDGC after acidic storage and aging for 14 days was slightly inferior compared with that of zirconia specimens, as they presented remarkable and clinically observable differences in color after acidic storage and aging.[34] The ΔE^* of zirconia CAD/CAM ceramic material was 2.63,[35] which was in parallel with the value (2.59) recorded in the present study. Alghazali et al.[13] showed that the ΔE^* values of zirconia and LDGC after AQ immersion are 1.82 and

1.58, respectively, which are lesser than the values obtained in the current study (2.63 for zirconia and 2.99 for LDGC). The difference may be related to the thickness of the ceramic materials, which was 1 mm for his study. The ΔE^* was higher after 2 weeks of AQ staining. Values higher than 2.63 and 2.99 were recorded for LDGC and zirconia after the examination of different CAD/CAM ceramic materials.[36]

The Ra values of the samples from each subgroup were analyzed. LDGC is biocompatible and has excellent physical and mechanical properties, such as high aesthetics, long color stability, surface gloss and luster, high wear resistance, and low thermal conductivity.[37] Al-Angari et al.[26] found an increase in Ra during Ra after the simulation of 1 year of coffee drinking. Similar results were recorded by Aldosari et al.[38] who concluded that the Ra values for zirconia, hybrid, and feldspathic CAD/CAM ceramics increased after AQ immersion for 14 days. In the current study, the computed Ra was slightly higher than those in other studies as confirmed by the images shown in Figures 2A to D.

AQ is widespread among Saudi populations and consumed twice daily. The null hypothesis correlating AQ immersion with biaxial fracture forces was rejected because significant differences in biaxial forces were found between the zirconia and LDGC subgroups (Table 5). Similar biaxial forces were published by Yilmaz and Okutan[39] who compared the biaxial flexure strengths of monolithic zirconia specimens with different surface treatments. They concluded that the air abrasion group after sintering had the highest average mean and SD for biaxial flexural strength (1043.37 ± 116.01 MPa), which is higher than the value recorded in the current study (656.10 ± 31.11 MPa). Both studies recorded remarkable differences between the tested groups. Another study documented a compressive strength near 800 MPa for glazed CAD/CAM ceramic material after thermocycling and khat immersion for 14 days.[19] From a clinical view, Jeong et al.[40] documented the 100% survival and success rates of fully sintered (Y,Nb)-TZP single-unit restorations at 6 months.[17]

Alahmari et al. found that no remarkable differences in two-way ANOVA tests for samples fabricated from lithium disilicate (e.max CAD) before and after aging and the fracture forces of the tested crowns. This result is because the tested samples were in the form of crowns.[14,41] Similar findings were recorded in the interactions between flexural strength and different types of monolithic zirconia ceramics (Celtra® DUO, Vita suprinity, and Bruxzir).[41] Yilmaz and Okutan showed an unremarkable interaction between the ceramic type and flexural strength of multilayered monolithic zirconia. This result could be explained by the different surface treatments used on the tested specimens along with hydrothermal aging.[40] Juntavee et al.[41] assessed the flexural strengths of different types of zirconia, and the recorded mean and SD values for the tested groups were 642.71 ± 92.54, 475.29 ± 76.81, and 522.65 ± 77.98 MPa. Similar values were obtained in the current study as presented in Table 5.

Fracture strength tests are usually used to estimate the behaviors of different oral prosthetic materials during functioning. Regarding fracture types, LDGC samples mostly showed reparable fractures. The present study recorded 40% reparable and semi-separable fractures. Al Moaleem et al. recorded the near-fracture percentages of zirconia samples, which were 30–70% and 40–60% for glazed and polished zirconia samples after thermocycling, respectively.[19] The same configurations of zirconia CAD/CAM samples after the application of biaxial fracture forces (Fig. 2D) were recognized microscopically by Juntavee et al. This configuration was represented as semi-reparable and recorded in 40 and 47% of the zirconia samples under white and black backgrounds.

Parallel significant differences were found in the interaction among ΔE^*, ceramic types (zirconia, hybrid ceramic, and feldspathic) and coffee staining materials.[37] Several studies demonstrated the considerable interaction among CAD/CAM ceramic materials (lithium disilicate, zirconia, and feldspathic), ΔE^*, and coffee staining materials.[42–44] A recent study by Theocharidou et al., examined and compared the impact of acidic storage and *in vitro* aging on the TP and ΔE^* values of CAD/CAM lithium disilicate and zirconia.[34] The two- and three-way ANOVA interactions showed remarkable differences among ceramic type, TP, and ΔE^*. This result partially agreed with the interaction tests carried out in the present study, because TP showed no remarkable differences in the present results. The differences in results could be related to differences in immersion and staining media (gastric acids vs AQ) and storage time (24 hours vs 14 days).

This study has the following limitations. First, the number of variables would increase if we added the result of the surface treatment test as a separate variable; but this result was not added as a variable in this study. Moreover, no uniform protocol for the simulation of the oral physiological situation of the soft and hard tissues of the oral cavity has been established; therefore, the current study does not reflect the exact oral environment.

Conclusion

Within the limitations of the current study, the following conclusions were drawn. The overall TP values of LDGC and zirconia were similar to values recorded in other researches with slight reduction after AQ staining. The ΔE^* values of LDGC and zirconia were within clinical acceptable range, without a remarkable difference. Zirconia groups only had remarkable differences in TP values under both backgrounds, whereas both zirconia and LDGC had notable variances in ΔE^* values under white background only. Biaxial fracture forces were higher in LDGC than in zirconia and had outstanding changes among zirconia samples in different backgrounds. Reparable type of fractures was the highest type with significant differences between and within groups.

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