THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Effect of different acidic solutions on the optical behavior of lithium disilicate ceramics

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ABSTRACT

Statement of problem. The stability of the optical characteristics of dental ceramics is essential. Degradation of these materials resulting from pH or temperature alterations in the oral cavity can lead to treatment failure.

Purpose. The purpose of this in vitro study was to evaluate the color change (ΔE), the L* coordinate, the translucency parameter, and the contrast ratio of lithium disilicate ceramic exposed to commonly used and potentially colorant solutions.

Material and methods. Fifty lithium disilicate specimens were prepared and divided into 5 groups according to the immersion solution (artificial saliva, orange juice, cola, coffee, and red wine). Immersions in acidic beverages were alternated in a thermocycler with artificial saliva. The control group was immersed in artificial saliva at 37°C throughout the immersion period. After 168 hours of immersion, the color parameters were assessed with a spectrophotometer and calculated using the because system on 2 backgrounds (black and white) and in 2 time periods, before thermocycling and after thermocycling. Data were submitted to analysis of variance followed by the Tukey honest significant difference test (α=.05).

Results. Greater color change (ΔE) and lower L* coordinate values were observed after immersion in orange juice and cola. Regarding the translucency parameter and contrast ratio, the immersion in coffee resulted in greater opacity and lower translucency of the material.

Conclusions. Alterations in the color stainability, the L* coordinate values, the translucency parameter, and the contrast ratio of the lithium disilicate ceramic were observed, according to the acidic solutions tested. (J Prosthet Dent 2017;118:430-436)

Dental esthetics have become increasingly important in contemporary society.[1,2] The demand for ceramic restorations has increased because of their enhanced esthetics and greater durability than other restorative materials.[3-5]

Development of dental ceramics has been promoted by overcoming clinically undesirable characteristic such as wear of antagonist teeth and restorations and difficulty controlling optical properties.[4] Creating restorations that mimic natural tooth appearance is one of the major clinical challenges.[6-8] The ceramic should reproduce natural tooth characteristics, including color, surface texture, and translucency, to achieve esthetic levels that accurately match the natural tooth structure.[6,7,9] The fabrication technique, method of application, and number of firing cycles affect ceramic properties.[4] The pressing technique promotes lower shrinkage during the manufacturing process, giving less surface porosity and higher resistance than with conventional ceramics.[10] This fabrication method is used for lithium disilicate ceramic, which has a unique crystalline phase (with 70% lithium disilicate crystals), providing a natural reflection of light on the

Supported by Scholarships for Initiation into Science (PIBIC)/National Council for Scientific and Technological Development (CNPq) scholarship 29651 to D.W.
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Clinical Implications

Commonly used acidic beverages influence the optical behavior of lithium disilicate ceramics. Greater color change was observed after immersion in orange juice and cola, and greater opacity and lower translucency were observed after immersion in coffee.

ceramic surface.[11,12] Ceramics are exposed to a surface degradation process, which occurs when they are exposed to aqueous solutions and/or pH alterations.[13-17] Furthermore, this process can be intensified by differences in temperature[13,15] and has undesirable consequences for the restoration, such as microbial plaque accumulation and restorations with alterations in color and appearance.[14,18] Many in vitro studies have shown that commonly used beverages such as coffee, tea, red wine, cola, and fruit juice can cause significant changes in the color of restorative materials.[19-31]

Maintenance of ceramic characteristics is essential from an esthetic perspective, because restorations that mimic only the shape and color of adjacent teeth are easily detected and can lead to treatment failure.[6,32-34] Color analysis by digital methods allows color measurement of restorative materials without the subjectivity of human analysis.[32,35-37] The CIELab system has the advantage of expressing data that can be related to visual perception, which has clinical significance.[12,38,39] However, Della Bona et al[4] reported that this system is unable to measure the opacity and translucency of the material. These optical phenomena are essential for color perception. Therefore, other methods, such as contrast ratio (CR) and translucency parameter (TP), are used to evaluate the translucency and opacity of esthetic materials.[6,40-43] Translucency parameter values are defined by the difference in color values obtained between the light reflected by a material with a defined thickness, positioned on 2 different backgrounds of black and white.[6,44,45] The CR values relate to the translucency of the material, ranging from 0.0 (transparent) to 1.0 (totally opaque).[6]

Studies of the influence of acidic diets on dental ceramics are rare.[46] Thus, this in vitro study evaluated the color change (ΔE), the L* coordinate, the TP value, and the CR of lithium disilicate ceramic exposed to commonly used and potentially colorant solutions. The null hypothesis was that the proposed solutions associated with temperature changes are not able to alter the optical properties of the tested ceramic.

MATERIAL AND METHODS

Fifty highly translucent lithium disilicate specimens (IPS e.max Press Impulse; Ivoclar Vivadent AG) (color O1) were prepared using the lost-wax technique from autopolymerized acrylic resin disks (Duralay; Polidental).[3] The resin disks were obtained from a metal, circular pattern (10-mm diameter, 3-mm thickness) and polished with metallographic abrasive papers (240, 400, 800, and 1200-grit; Buehler Ltd) in an automated polishing machine (Aropol-2V; Arotec).

The acrylic resin disks were placed on a coating ring with the investment (IPS PressVEST; Ivoclar Vivadent AG), and the ceramic was injected through sprues at 915°C to 920°C, after which a ring gauge (IPS Ring Gauge; Ivoclar Vivadent AG) was placed over the ring. After solidification, the gauge and base rings were removed, and irregularities on the inferior part of the ring were removed. The investment ring was then inserted into a preheated furnace (EP 5000; Ivoclar Vivadent AG) for 45 minutes at 850°C to eliminate the acrylic resin. Subsequently, the pressing channel was filled with a ceramic ingot, and the ceramic was injected by using a plunger (IPS e.max Alox Plunger; Ivoclar Vivadent AG). The entire assembly was carried to the furnace to start the injection cycle for 60 minutes. After cooling, the investment material was removed using glass beads at 200 kPa pressure. The lithium disilicate specimens were then airborne-particle abraded with aluminum oxide (Al_2O_3; Bio-Art) at 200 kPa, and the sprues were removed with a diamond rotary instrument at low speed and with light pressure to avoid overheating.

The specimen thickness was measured with calipers (500-171-20B; Mitutoyo) before the cleaning procedure.[47] Subsequently, the specimens were cleaned in an ultrasonic bath with distilled water to remove surface impurities. The glaze firing was performed afterward, according to the manufacturer's recommendations.

The specimens were divided according to the immersion solutions into 5 groups (n=10): group S (artificial saliva), group OJ (orange juice), group CC (cola [Coca-Cola]), group C (coffee), and group RW (red wine) (Table 1). The specimens from group S were stored in artificial saliva in an incubator at 37°C for 168 hours. The specimens from groups OJ, CC, C, and RW were immersed in their respective acidic beverages and also alternated with immersion in artificial saliva in a thermocycler (MSCT-3; Convel), because acidic drink consumption is not continuous but interspersed with exposure to saliva.[49]

Specimens were stored in deionized water in a digital incubator (CE-210; CIENLAB) at 37 ±1°C for 24 hours before the initial readings and immersion protocol.[19] For the thermocycling process, the acidic beverages were stored in a container positioned inside the incubator. Another container in the incubator had artificial saliva stored at 37°C. The temperature of the beverages was 5°C or 55°C, as listed in Table 1.[19] A total of 10 080 cycles of 1 minute each were performed. This cycle scheme

Table 1. Immersion solutions used

Immersion Solution	Manufacturer	Chemical Composition	pH	Immersion Temperature[19,48]
Artificial saliva	Sigma-Aldrich Brazil Ltda	KCl (0.4 g L^{-1}), NaCl (0.4 g L^{-1}), $CaCl_2\_2H_2O$ (0.906 g L^{-1}), $NaH_2PO_4\_2H_2O$ (0.690 g L^{-1}), $Na_2S\_9H_2O$ (0.005 g L^{-1}), and urea (1 g L^{-1})	6.5	37°C
Orange juice	Coca-Cola	Orange juice, water, sugar, orange pulp, natural flavors, antioxidant ascorbic acid, and citric acid	3.52	5°C
Cola	Coca-Cola	Carbonated water, sugar, cola nut extract, yellow dye IV, acidulant INS 338, and natural flavors	2.49	5°C
Coffee	Sara Lee Cafes do Brazil Ltda	Roasted and ground coffee	5.35	55°C
Red wine	Jose Maria da Fonseca	Red grape varieties, conservative INS 220, sulfuric acid, 12.7%	3.58	5°C

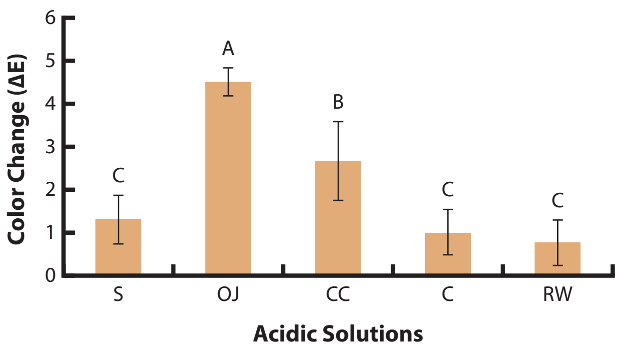

Figure 1. Mean values of color change (ΔE) on black background of ceramic for different immersion solutions used. Different uppercase letters denote statistically significant differences ($P<.05$; Tukey honest significant difference test). C, coffee; CC, Coca-Cola; OJ, orange juice; RW, red wine; S, artificial saliva.

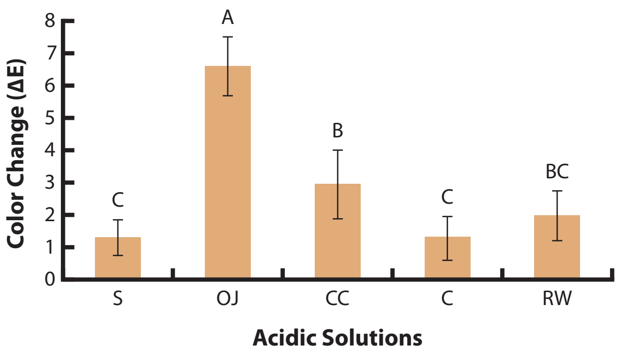

Figure 2. Mean values of color change (ΔE) on white background of ceramic for different immersion solutions used. Different uppercase letters denote statistically significant differences ($P<.05$; Tukey honest significant difference test). C, coffee; CC, Coca-Cola; OJ, orange juice; RW, red wine; S, artificial saliva.

corresponded to 168 hours, which simulated 22 years of clinical performance of a ceramic restoration.[14,50-52] After thermocycling, the specimens were washed in running water and dried in absorbent paper before the color measurements were made.[53]

The color parameters were assessed using a spectrophotometer (UV-2450; Shimadzu) on 2 backgrounds (black and white).[6] The measurements were made using a D65 illuminant at a 2-degree angle of observation, a wavelength range of 380 to 780 nm, and a 10-mm-diameter aperture. One reading per specimen was made in 2 time periods, before and after thermocycling. The color changes (ΔE) were calculated using the CIELab system, as established by the Commission Internationale de I'Eclairage (CIE).[38,54] This system calculates the color variation between 2 points in a 3-dimensional (3D) color space.[38,44,45,54] The L* coordinate values on white and black backgrounds were also evaluated.

The translucency of a material can be quantitatively described through the calculation of the CR and TP values, each involving an optical measurement performed on a specific thickness.[6,41] The specimens were placed on black and white backgrounds, and the values were recorded using CIELab coordinates for the CR and TP calculations.[6] Data were submitted to 1-way analysis of variance (ANOVA) for the color change (ΔE) and 2-way repeated-measures ANOVA for the L* coordinate, CR, and TP values. The Tukey honest significant difference test (α=.05) was used for all analyses.

RESULTS

The type of immersion solution influenced the color change (ΔE) of the lithium disilicate ceramic on black (df=4; F=68.276; $P<.001$ by ANOVA) and white (df=4; F=74.254; $P<.001$ by ANOVA) backgrounds. Greater color change (ΔE) was observed after immersion in orange juice (4.51 on black and 6.58 on white backgrounds), followed by cola (2.67 on black and 2.95 on white backgrounds), with statistically significant differences from the other groups (Figs. 1, 2).

The L* coordinate of the lithium disilicate ceramic was affected by the immersion solution on the black background ($P<.001$) (Table 2) and by the interaction between the type of solution and period of analysis on the white background ($P<.001$) (Table 3). After thermocycling, statistically lower L* coordinate values were found for cola (47.64 on black and 65.44 on white backgrounds), followed by orange juice (52.71 on black and 70.65 on white backgrounds) (Figs. 3, 4).

The interaction between the type of immersion solution and the period of analysis (before and after

Table 2. Two-way repeated-measures ANOVA of ceramic for L* coordinate on black background for different immersion solutions

Variation Factor	*df*	Sum of Squares	Mean of Squares	F	*P*
Solution	4	1708.911	427.228	52.269	<.001
Between subjects	45	367.813	8.174		
Period	1	3.644	3.644	1.236	.272
Solution×period	4	11.687	2.922	0.991	.422
Within subjects	45	132.682	2.948		

P<.05 denotes statistically significant difference.

Table 3. Two-way repeated-measures ANOVA of ceramic for L* coordinate on white background for different immersion solutions

Variation Factor	*df*	Sum of Squares	Mean of Squares	F	*P*
Solution	4	637.210	159.303	73.558	<.001
Between subjects	45	97.456	2.166		
Period	1	39.464	39.464	27.153	<.001
Solution×period	4	105.781	26.445	18.196	<.001
Within subjects	45	65.402	1.453		

P<.05 denotes statistically significant difference.

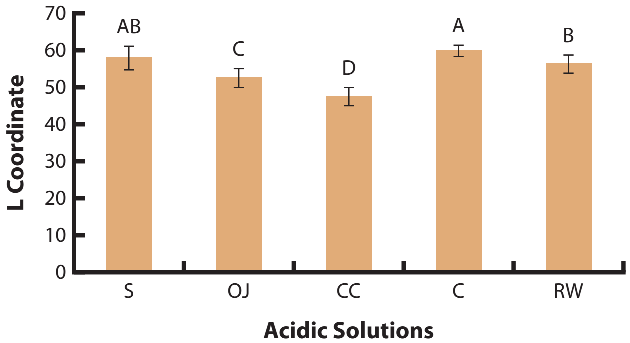

Figure 3. Mean values of L coordinate values on black background of ceramic after immersion in different immersion solutions. Different uppercase letters denote statistically significant differences (*P*<.05; Tukey honest significant difference test). C, coffee; CC, Coca-Cola; OJ, orange juice; RW, red wine; S, artificial saliva.

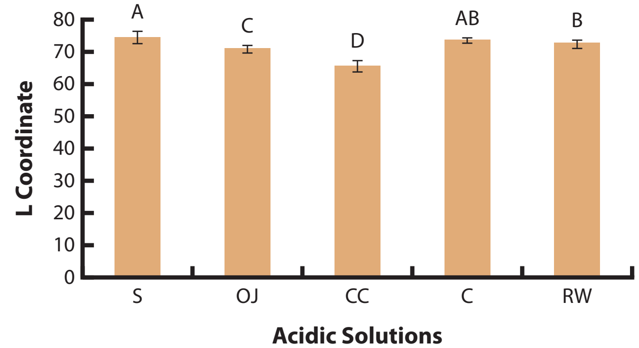

Figure 4. Mean values of L coordinate values on white background of ceramic after immersion in different immersion solutions. Different uppercase letters denote statistically significant differences (*P*<.05; Tukey honest significant difference test). C, coffee; CC, Coca-Cola; OJ, orange juice; RW, red wine; S, artificial saliva.

Table 4. Two-way repeated-measures ANOVA of ceramic for translucency parameter for different immersion solutions

Variation Factor	*df*	Sum of Squares	Mean of Squares	F	*P*
Solution	4	461.614	115.403	19.328	<.001
Between subjects	45	268.684	5.971		
Period	1	7.415	7.415	3.207	.080
Solution×period	4	78.269	19.567	8.464	<.001
Within subjects	45	104.034	2.312		

P<.05 denotes statistically significant difference.

thermocycling) significantly affected the results (*P*<.001) (Table 4) in regard to the ceramic TP. The TP value was lower for specimens immersed in coffee, with a statistically significant difference from those values of the other solutions (Fig. 5).

The interaction between the type of immersion solution and the period of analysis significantly affected the results (*P*=.009) (Table 5) in regard to the CR of the ceramic. The immersion in coffee resulted in greater opacity of the material (Fig. 6).

DISCUSSION

The null hypothesis that the tested solutions were not able to promote alterations in the optical properties of the tested ceramic was rejected. Color changes and alterations of the TP and CR values were observed. The

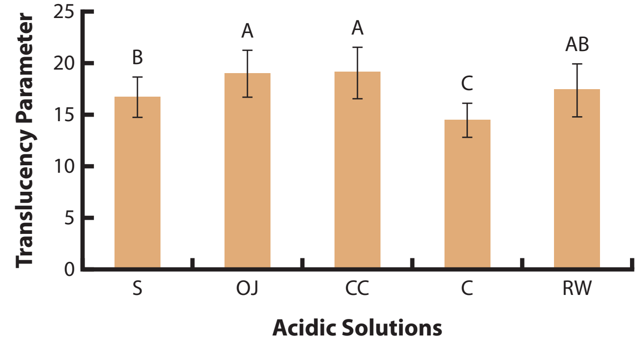

Figure 5. Mean values of translucency parameter of ceramic after immersion in different solutions. Different uppercase letters denote statistically significant differences (*P*<.05; Tukey honest significant difference test). C, coffee; CC, Coca-Cola; OJ, orange juice; RW, red wine; S, artificial saliva.

Table 5. Two-way repeated-measures ANOVA of ceramic for contrast ratio for different immersion solutions

Variation Factor	*df*	Sum of Squares	Mean of Squares	F	*P*
Solution	4	0.375	0.094	24.103	<.001
Between subjects	45	0.175	0.004		
Period	1	0.000064	0.000064	0.044	.834
Solution×period	4	0.22	0.006	3.832	.009
Within subjects	45	0.065	0.001		

P<.05 denotes statistically significant difference.

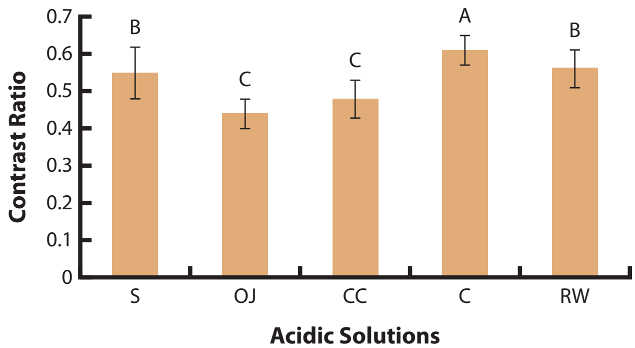

Figure 6. Mean values of contrast ratio of ceramic after immersion in different solutions. Different uppercase letters denote statistically significant differences ($P<.05$; Tukey honest significant difference test). C, coffee; CC, Coca-Cola; OJ, orange juice; RW, red wine; S, artificial saliva.

immersions in orange juice and cola were responsible for greater color change (ΔE) and lower L* coordinate values on the black and white backgrounds. The immersion in coffee resulted in greater opacity and lower translucency of the material in regard to the TP and CR.

The CIELab system, used for the analysis of color change (ΔE), quantifies color changes through 3D coordinates. The L* parameter evaluates the luminosity (scale, 0-100, where 0 represents black and 100 represents white), the a* coordinate measures the amount of redness (positive values) and greenness (negative values), and the b* coordinate measures the amount of yellowness (positive values) and blueness (negative values).[6,38,54] This system was chosen because it identifies small color differences among specimens and has been widely used.[27,39] Two backgrounds (black and white) were used to analyze the optical properties. Because the black background is more absorbent, it is used to simulate the clinical situation of anterior teeth, whereas the white background is used for posterior teeth.[27]

Although statistically significant differences were observed for orange juice and cola when they were compared with other groups, only the immersion in orange juice resulted in ΔE values greater than 3.3 (4.51 on black and 6.58 on white backgrounds); a color change perceptible to the human eye and clinically unacceptable.[5,27,31] According to Hipólito et al,[38] the pH of the solution in which the specimen is immersed influences its color change. Although the cola drink presented the lowest pH among the tested solutions, which may damage the surface integrity of the material, a color change perceptible to the human eye was not observed, possibly because of the low amount of yellow colorant in its composition.[26,30] Furthermore, while the cola drink contains carbonic and phosphoric acids in its composition, the orange juice contains citric acid, which may explain the differences found according to Catelan et al.[26]

Damage to the surface integrity of the ceramic is associated with exposure to a low pH condition, which results in the dissolution of the silica in its composition and in the loss of alkaline ions.[17] As a result, a surface degradation occurs and may result in a higher penetration of colorants and, consequently, greater discoloration of the material.[30] Therefore, the optical change observed is not an intrinsic color change of the ceramic but a result of its surface degradation and extrinsic color additions.

The value of the color change (ΔE) is considered the gold standard for measurement analysis, but only the CIELab coordinates are considered without other criteria such as translucency, opalescence, fluorescence, brightness, surface texture, and shape[6,12] being evaluated. The present study included the evaluation of the TP and the contrast ratio for a more complete chromatic analysis of the material; the greater the value of the TP, the greater the translucency of the material. Lithium disilicate ceramic has excellent translucency because of a high content of lithium disilicate crystals[11,12] This advantage must be preserved for the longevity of the rehabilitation. In the present in vitro study, immersion in coffee resulted in lowering the TP of the material.

Concerning the CR values, the greatest opacity of the ceramic was found after thermocycling with immersion in coffee. Coffee contains yellow colorants with lower polarity, which result in a discoloration of the material caused by adsorption and absorption of colorants.[22,30] This beverage was the only one submitted to higher temperatures (55°C) to simulate its daily use, a factor that may have influenced the greater opacity and lower translucency of the ceramic.

Bagis and Turgut[39] evaluated the optical properties of different ceramic systems, including lithium disilicate ceramics before and after accelerated aging. The authors observed that the specimens became more opaque, darker, reddish, and yellowish after accelerated aging, using ultraviolet light and water spray. It was performed for 300 hours, which simulated 1 year of clinical use. However, this alteration was not clinically perceptible. Similarly, Dikicier et al[34] found darkening of the lithium disilicate ceramics after aging for 200 hours also clinically undetectable.

Most of the studies evaluating the optical properties of restorative materials continuously immersed the specimens in colorant beverages, complicating the correlation between the study and what is found clinically, because exposure of the restoration to such beverages is alternated with periods of exposure to saliva. Additionally, studies should include cycling of the materials in solutions at different temperatures, simulating the laboratory conditions of the oral environment more faithfully.[18,19] Furthermore, in the present study, the temperature usually used for the intake of the beverage was replicated, with a higher temperature for the coffee and lower temperatures for the cola, orange juice, and red wine. This is because temperature differences can interfere with color change because they influence the surface porosity of the material.[3]

The present study has some limitations, and other methodologies have been reported for optical property analysis. An alternative method of measuring the color of the specimens is the Kubelka-Munk theory.[55] This methodology is a reflectance theory for layers on a backing and is a mathematical model which describes the reflectance resulting from 2-flux radiation transfer in a homogenous and uniform medium on an opaque backing. Through this method, the reflectance and transmittance of the specimen can be evaluated.[55-57]

The results of the present in vitro study are of clinical relevance because they provide information related to the effect of acidic solutions on the optical properties of lithium disilicate ceramics. Patients using these restorations should avoid regular consumption of orange juice, cola, and coffee, aiming for less stainability of the optical properties of this material. However, because it is an in vitro study, randomized clinical trials are necessary for long-term evaluation of the optical properties of lithium disilicate ceramic.

CONCLUSIONS

From the findings of this in vitro study, the following conclusions were drawn:

1. Immersion in orange juice and cola resulted in greater color changes (ΔE) and lower L* coordinate values.
2. Immersion in coffee resulted in greater opacity and lower translucency of the material.

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