EGYPTIAN DENTAL JOURNAL
www.eda-egypt.org
VOL. 69, 1435:1451, APRIL, 2023
PRINT ISSN 0070-9484 • ONLINE ISSN 2090-2360
FIXED PROSTHODONTICS AND DENTAL MATERIALS
Submit Date : 04-02-2023 • Accept Date : 08-02-2023 • Available online: 10-04-2023 • DOI : 10.21608/edj.2023.191307.2424

TRANSLUCENCY, MICROHARDNESS AND FRACTURE TOUGHNESS OF TWO MACHINABLE CERAMICS AS AFFECTED BY TWO ACIDIC BEVERAGES

Rasha. N. Sami*

ABSTRACT

Statement of the Problem: Alterations of pH in the oral cavity can lead to degradation of machinable esthetic materials that mimic the natural tooth appearance resulting in an esthetic failure. Hence, the stability of the optical and mechanical characteristics of these materials is essential for a long-term successful restoration.

Aim of the Study: To evaluate the translucency, microhardness, and fracture toughness of two CAD/CAM materials (IPS e.max CAD and Vita Enamic) after immersion in two acidic beverages (Coffee and Coca-Cola).

Materials and methods: A total of 36 samples were equally divided into two groups each (n=18) as follows, Group I: IPS e.max CAD and Group II: Vita Enamic. Each group was further subdivided into two subgroups (n=9) according to the acidic beverage used, either Coffee, or Coca-Cola. Samples were immersed in acidic beverage solutions for three weeks, after which all samples were subjected to measure the translucency parameter using a Reflective Spectrophotometer and then using Vickers Micro-Hardness Tester to measure surface microhardness and fracture toughness. Statistical analysis was performed using one-way analysis of variance followed by Tukey's post-hoc test if showed significance. Student t-test was done between main groups, while Two-way ANOVA compared the effect of each factor.

Results: There was a statistically significant difference between IPS e.max CAD and Vita Enamic regarding translucency. Significant difference in surface microhardness, and fracture toughness after immersion in two acidic beverage solutions was revealed.

Conclusions: Acidic beverages can adversely affect the translucency of glass-ceramic and hybrid ceramic materials. Microhardness and fracture toughness of different CAD/CAM esthetic materials was negatively affected secondary to exposure to beverages with low pH values.

KEYWORDS: Translucency Parameter, acidic beverage, hybrid-ceramic, glass-ceramic, microhardness, fracture toughness.

*Associate Professor, Fixed Prosthodontics Department, Faculty of Dentistry, Cairo University

INTRODUCTION

The increased popularity of biomimetics and bio-emulation idea in esthetic dentistry has been associated with the massive use of restorations that mimic the natural tooth color [1]. With a rising trend of CAD/CAM systems and the increased patients' esthetic demands, several machine milled esthetic materials have been widely elaborated with different components. These materials should replicate teeth surface characterizations such as form, shape, color, and translucency, to reach a convenient esthetic level that precisely coincides with the tooth normal structure[2,3]. Lithium disilicate (IPS e.max) is part of the glass-matrix ceramic division which possesses a distinctive crystalline form (with 70% lithium disilicate crystals), that allows a natural reflection of light on its surface[4]. It became popular for the construction of fully anatomic single anterior and posterior restorations because of its superior optical and esthetic properties [5]. On the other hand, in 2013, a ceramic network of a fine structure feldspathic ceramic that has been infiltrated by a polymer (PICN) VITA Enamic which belongs to the hybrid ceramic category was developed[6]. It consists of a ceramic part (75% by volume) and a polymer part (25% by volume). Its ceramic phase includes 23% Al_2O_3 and the polymer part contains urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEGDMA)[7]. Such material was introduced to obtain a material that possesses a modulus of rigidity similar to that of natural dentition, easily milled, and easier to be intra-orally repaired[8].

These ceramic materials should have a superior color match and maintain its color during clinical service[9]. Perseverance of different ceramics in the oral cavity relies upon several factors among which is their microstructure, components and processing procedures, the pH intra-orally, extent of exposure, and the warmth of chemical agents[10]. Several determinants within the oral environment may impede the durability of restorations by badly affecting their properties. Exposure to corrosive agents will result in destruction of the ceramics with the release of alkaline ions. Deterioration of such materials will lead to an increase in their surface roughness resulting in an abrupt reduction in their strength with a growing tendency to discoloration[11,12]. On the other hand, the color instability of composites could be either due to external or internal reasons[13]. The external factors incorporate the effect of staining solutions such as caffeine-containing beverages, colored beverages, food, and smoking habits[14]. While the internal factors depend mainly on the material composition, duration of polymerization, change in the monomers of the resin-matrix, particle size and hardness, and the reaction of oxygen with the unreacted carbon double bonds[15].

The use of digital methods for color analysis allowed color assessment of different restoration materials with an exclusion of the subjectivity of human analysis[16-19].

Despite, having the ability of manifesting data associated with visual perceptivity, that has clinical importance [20,21], yet, the CIELab system does not have the ability to measure the opacity and translucency of the material, as reported by Della Bona[22]. These optical phenomena are essential for color perception. Therefore, other methods, such as contrast ratio (CR) and translucency parameter (TP), have been recommended to measure the translucency and opacity of esthetic materials[23-25].

Translucency parameter is defined by the color difference attained between the light reflected by an object of a known thickness and placed over two different black and white backgrounds[26-28]. The CR values is also an estimate for translucency of the material, with a range from (0.0 to 1.0) which resembles a material (transparent to totally opaque)[26].

Mechanical properties as well are one of the crucial components to be considered when choosing a restoration to service in the oral cavity. Restorative materials replacing missing dental tissues must be

powerful enough to resist the masticatory forces[29,30]. Hardness is an acceptable indicator of the mechanical nature of dental materials and is defined as the materials withstanding to permanent indentation or perforation. Hardness can have a strong effect on the milling tendency, degree of surface polish and resistance to wear different restorative materials, moreover it is commonly affected ageing, water absorption and surface reactions[31]. Although several tests have been advocated to measure hardness, among which is the Martens, Knoops, and Vickers, yet most of the investigators commonly use Vickers microhardness tests to examine and evaluate the hardness of dental materials [32].

Although fracture is considered as one of the most common causes of failure for dental restorations in clinical practice[33], yet fracture toughness which indicates how the material might behave under different clinical conditions is proven to be one of the clinically relevant mechanical properties. It is known to be the ability of the material to withstand propagation of cracks within it [34]. Consequently, the importance of how an acidic erosive agent can affect the materials' potential to counter the propagation of any possible surface defects induced by the erosive acids should be clearly investigated.

Therefore, this study design focused upon evaluating and comparing the translucency parameter, micro-hardness, and fracture toughness of two machinable materials of high esthetic qualities after being exposed to acidic beverages with different pH values among which are the coffee and Coca-Cola, the most consumed beverages amongst individuals[14]. Three null hypotheses were postulated. Firstly, that there will be no significant difference in the translucency of both materials. Secondly, regarding the microhardness of the two tested materials, non-significant difference will be found. Finally, the third null hypothesis assumed that the difference in the fracture toughness of both CAD/CAM materials under investigation will be insignificant.

MATERIALS AND METHODS

A. Study design and sample estimation:

Based on a previous study Alsilani et al[35], it was found that a sample size of 18 per group possess an 80% power to detect an increase of 0.50 with a significance level (alpha) of 0.05 (two-tailed) and 95% confidence intervals. In 80% the power of those experiments, the P value will be less than 0.05 (two-tailed) so the results are to be considered "significant statistically". In the remaining 5% of the experiments, the increase will be rated "insignificant statistically". Report created by GraphPad StatMate 2.00.

B. Samples distribution and preparation:

For standardization purposes throughout this study, and from the two CAD/CAM esthetic materials tested a total of thirty-six, square-shaped samples for were prepared and fabricated. According to the type of material used, samples were equally divided into two groups (n=18) each, Group I: IPS e.max CAD; (Ivoclar Vivadent AG) with shade A2 LT and block size 14, Group II: Vita Enamic (VITA Zahnfabrik) hybrid ceramic with shade 2M2-T. Furthermore, every group was subdivided at random into two equal subgroups each (n=9), to test their translucency, micro-hardness, and fracture toughness, according to the acidic beverage used, (Coffee, and Coca-Cola). Materials used and their composition are mentioned in Table (1).

With the aid of the isoMet 4000 electric microsaw (Buehler, USA), blocks from each material were sectioned into samples (10 X 14) mm in dimensions and of 1mm thickness. Sawing was carried out under a running water coolant via the Buehler diamond disc (Renfert GmbH, Germany) with a speed of 2500 rpm and a feeding rate of 13.7 mm/min. After each cutting process the thickness was checked with the aid of a digital caliper.

TABLE (1) Materials used in this study:

Materials (Commercial names)	Type/description	Chemical composition (in wt%)	Manufacturer
IPS e.max CAD blocks	Lithium disilicate glass-ceramic shade LT A2 size: C14	SiO_2 57.0-80.0 Li_2O. 11.0-19.0 K_2O 0.0-13.0 P_2O_2 0.0-11.0 ZrO_2 0.0-8.0 ZnO 0.0-8.0 other 0.0-10.0 colouring oxides 0.0-8.0	Ivoclar Vivadent, Schaan, Liechtenstein. Canada
Vita Enamic CAD/CAM blocks	Innovative hybrid ceramic shade: 2 M2-T size: EM-14	***86% fine-structure feldspathic ceramic*** SiO_2 58-63 AL_2O_3 20-23 NaO_2 9-11 K_2O, 4-6 ZrO_2 0-1 ***14% polymer*** (urethane dimethacrylate) **UDMA**, (triethylene glycol dimethacrylate) **(TEGDMA)**	VITA Zahnfabrik, Spitalgasse 3. Germany
Artificial saliva	Artificial saliva	2.2 g/L gastric mucin, 0.381 g/L sodium chloride, 0.231 g/L calcium chloride, 0.738 g/L potassium phosphate, 1.114 g/L potassium chloride, 0.02 sodium azide, trace of sodium hydroxide. **PH=7.0.**	Biochemistry lab, Faculty of Medicine Cairo University, Egypt
Coffee	Nescafe Gold Instant soluble freezes dried coffee	Caffiene, theobromine, theophylline, thiamine, xanthine, tannin, tannic acid, citric acid, chlorogenic acid, spermidine, acetaldehyde, spemine, scopoletin and phenols. **PH=5.8**	Nestle, Switzerland
Coca-Cola	Coca-Cola beverage	Carbonated water, sugar, phosphoric acid, caramel colour, natural flavours, and sodium **PH=2.5**	Cairo, Egypt

C. Surface treatment of samples

For all sliced samples of Group I: IPS e.max CAD a crystallization cycle was carried out to reach their maximum magnitude of strength and develop their final shade as they were sliced in the pre-crystallized blue stage form, therefore, At first, the crystallization cycle started with a pre-drying phase of all samples for 2 minutes at 403° C in the summit press furnace (IBEX dental technology, USA) under vacuum. After that temperature was raised in a constant manner till it reached 850° C, then held for 9 minutes at a rate of 50° C/min to be certain of the crystallization of the IPS e.max CAD. After the crystallization cycle was accomplished, the furnace opened, to allow the samples to cool down for 15 minutes.

To reach a flat surface which was of paramount importance for color parameters measurement, in order to ensure evenness throughout the procedural steps, finishing and polishing of all samples were

carried out by the same investigator. For Group I: after polishing using a cotton puff wheel brush, a glaze was added on one surface of the IPS e.max CAD samples (clear glaze, Cerabien ZR, FC, Kuraray) then fired on a furnace tray (SUMMIT Press furnace; IBEX Dental Technologies, USA) following the proposal of the manufacturer. While for Group II: Vita Enamic samples were manually polished in a two-step polishing procedure by Vita Enamic Polishing Set technical (VITA Zahnfabrik). Firstly, pink silicon carbide pre-polishing discs were used after which the grey high gloss polishing discs were used following manufacturer's recommendations.

D. Samples Immersion

Prior to any assessment and as a (baseline) before immersion in any of the acidic beverages, all samples both groups, were submerged in 20 ml of artificial saliva for 24 hours. Then removed from artificial saliva and blot dried. The color of each sample was assessed using a Reflective spectrophotometer (Model RM200QC, X-Rite, Neu-Isenburg, Germany). Figure (1)

Fig. (1) Reflective spectrophotometer

For coffee subgroup of both groups, a 200 mL boiling distilled water was prepared in a beaker in which a 5g sachet of Nescafe Gold coffee powder (Nestle, Switzerland) was dissolved, after stirring for 10 minutes according to the directions of use. Then, solution was filtered through a filter paper. Eighteen firmly closed glass containers were prepared and filled with 1mL of coffee after which, nine samples from each group were immersed separately in them. Samples were kept in an incubator (CBM. Torre Picenardi (CR), Model 431/V, Italy) for 3 weeks at a constant temperature at 37°C, which simulate the consumption of one cup of coffee per day for 21 months[36]. To ensure homogeneity, the glass containers were agitated every 3 hours, coffee solutions were renewed regularly every day to avoid any change or settling of the solution.

For the Coca-Cola subgroup of both groups, using a plastic syringe and from a 250 mL Coca-Cola bottle (Cairo, Egypt) 1 mL of Coca-Cola was extracted to fill eighteen glass vessels, nine for each group. Each sample was submerged separately in a glass container tightly closed, and were stored at 37°±1°C in an incubator and daily renewed for 3 weeks, as it was proven to resemble a daily consumption of one glass of this beverage for 21 months [36]. After 3 weeks, all samples for both tested beverage solutions were carried away by a pair of tweezers, rinsed with running distilled water then by using a clean tissue paper all investigated samples were dried to be ready for the different measuring tests.

i. Color measurements:

i.a. Color change (ΔE)

Using a Reflective spectrophotometer (X-Rite, model RM200QC, Neu-Isenburg, Germany), all tested samples of both groups and subgroups were subjected to color measurements. The opening size through which light passes was adjusted to 4 mm and the specimens were accurately placed within the device. By choosing a white background, measurements were carried out according to the

CIE L*a*b* color space relative to the CIE standard illuminant D65. The color changes (ΔE) of the specimens were estimated by the below formula:

$$\Delta E_{CIELAB} = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})\ ½$$

Where: L* = lightness (0-100), a* = (change the color of the axis red/green) and b* = (color variation axis yellow/blue)[37]

i.b. Translucency parameter (TP)

To assess the translucency parameter, all samples from both groups and subgroups were measured using the previously mentioned Reflective spectrophotometer. At a mid-point of each sample, measurements equivalent to the CIE standard illuminant D65 were conducted over a ***white*** (CIE L*= 88.81, a*= -4.98, b*= 6.09) and ***black*** (CIE L*= 7.61, a*= 0.45, b*= 2.42) backing. The samples were oriented in the center of the measuring aperture and were secured in a steady fixed position for the two backings.

The translucency parameters (TP) values were derived by calculating the color difference of the samples over black and white backgrounds by using the following equation:

$$TP = [(L_b^* - L_w^*)^2 + (a_b^* - a_w^*)^2 + (b_b^* - b_w^*)^2\ ]^{1/2}$$

where letters "b" and "w" refer to color coordinates over the black and white backgrounds, respectively[38].

ii. Micro-hardness testing:

Utilizing a Digital Display Vickers Micro-hardness Tester (Model HVS-50, Laizhou Huayin Testing Instrument Co., Ltd. China) with a Vickers diamond indenter and a 20X objective lens Figure (2), values of surface micro-hardness were obtained for the tested samples after submerging in the different beverages. A 100g of load was applied to the surface of the samples for 15 seconds. Three indentations were performed and equally placed on the surface of each specimen over a circle and not closer than 0.5 mm to the adjacent indentations. The length of the diagonal's indentations was measured by built-in scaled microscope and Vickers values were transformed to micro-hardness values.

Micro-hardness was obtained using the following equation:

$$HV = 1.854\ P/d^2$$

where, HV is Vickers hardness in Kgf/mm², P is the load in Kgf and (d) is the length of the diagonals in mm.

Fig. (2) Vickers Micro-hardness Tester

iii. Fracture toughness measurement:

From three indentations made on each sample, fracture toughness was estimated by the indentation technique[39-41]. The general concept of this technique is based upon a set of cracks performed in a brittle material around a Vickers diamond indenter after heavy load application. With an upward view of the specimens, cracks seem to develop from each of the corners of the indentation. The extent of such cracks, demonstrated by surface dimension "c," increases with increased indentation load and is an inverse outcome of fracture toughness Figure (3). Hence, the fracture toughness was computed from the hereunder equation:[42].

$$K_{IC} = 0.016(E/H)^{0.5}(P/c^{1.5})$$

where K_{IC} is the fracture toughness, c is the crack length, which is the half diagonal of the indentation, *(measured from the center of the indentation)*, P is the applied indenter load, H is the Vickers hardness and E is the elastic modulus for each material tested

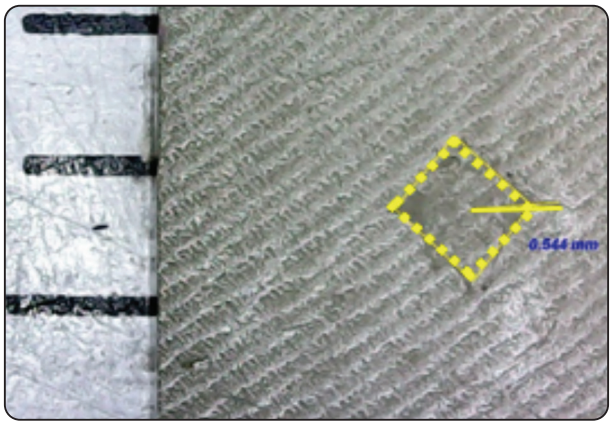

Fig. (3) Indentation technique for fracture toughness

RESULTS

The results were analyzed using Graph Pad Instat (Graph Pad, Inc.) software for windows. A value of $P \leq 0.05$ was considered significant statistically. Continuous variables were expressed as the mean and standard deviation. After homogeneity of variance and normal distribution of errors had been confirmed, one-way analysis of variance was performed followed by Tukey's post-hoc test if showed significance. Student t-test was done between main groups. Two-way ANOVA compared the effect of each factor "type of material and acidic beverage solution". Sample size (n=18/group) was sufficient to perceive large effect sizes for main effects and pair-wise comparisons, with the satisfactory level of power set at 80% and a 95% confidence level.

III. i. Color change (ΔE):

Color change (ΔE) results as (Mean±SD) for both groups after immersion in acidic beverages solutions were shown numerically in Table (2) and graphically in Figure (4) as follows.

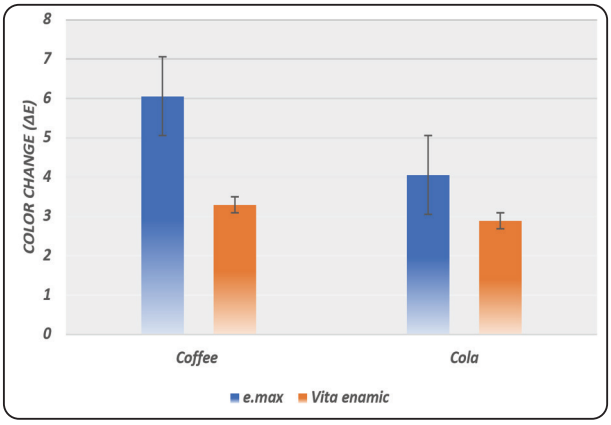

Fig. (4) Column chart of the mean values of color change for both groups after immersion in acidic beverage solutions

For Group I: IPS e.max CAD, it was found that the Coffee subgroup recorded statistically significant higher color change mean (6.06±0.35 ΔE) than Coca-Cola subgroup (4.06±0.91 ΔE) as demonstrated by paired t-test tests (P=<0.0001< 0.05)

For Group II: Vita Enamic, it was found that the Coffee subgroup recorded statistically significant higher color change mean (3.29±0.26 ΔE) than Coca-Cola subgroup (2.89±0.35 ΔE) as verified by paired t-test tests (P=0.0132< 0.05)

TABLE (2) Color change results (ΔE) for both groups after immersion in acidic beverage solutions

Variable		Treatment solution		ANOVA test
		Coffee	Cola	P value
IPS e.max CAD	Mean±SD	6.06±0.35	4.06±0.91	<0.0001*
	95% CI (low-high)	5.83–6.29	3.46–4.65	
Vita Enamic	Mean±SD	3.29±0.26	2.89±0.35	0.0132*
	95% CI (low-high)	3.13–3.47	2.66–3.12	
t-test	P value	<0.0001*	0.003*	

CI; confidence intervals
****; significant (p < 0.05)***
ns; non-significant (p>0.05)

- ***Effect of the two CAD/CAM materials***, regardless to the acidic beverage solution, differences observed between groups were statistically significant as revealed by two-way ANOVA test (p=<0.0001 < 0.05) where (IPS e.max CAD >Vita Enamic).
- ***Effect of the two acidic beverage solutions***, irrespective of the group it was noticed that the acidic beverage solutions had a significant effect on mean values as verified by two-way ANOVA test (p=<0.0001< 0.05) where (Coffee > Coca-Cola).

III. ii. Translucency parameter (TP):

Translucency parameter (TP) results (Mean±SD) for both groups before (baseline) and after immersion in acidic beverages solutions were presented numerically in Table (3) and graphically in Figure (5) as follows.

For Group I: IPS e.max CAD, the highest mean ± SD values of translucency parameter were detected before (baseline) immersion subgroup (18.53±1.245 TP) followed by Coca-Cola subgroup mean ± SD values (13.09±1.634 TP) meanwhile the lowest mean ± SD values were recorded with Coffee subgroup (12.2±0.887 TP). The difference among subgroups was statistically significant as proven by ANOVA test (P=<0.0001< 0.05). Tukey's post-hoc pair-wise tests showed non-significant (p > 0.05) difference between (Coffee and Coca-Cola) subgroups.

For Group II: Vita Enamic, it was found that the highest mean ± SD values of translucency parameter were recorded ***before*** immersion subgroup (17.839±0.871 TP) followed by Coca-Cola subgroup mean ± SD values (15.78±2.067 TP) meanwhile the lowest mean ± SD values were recorded with Coffee subgroup (14.297±0.221 TP). The difference between groups was statistically significant as proved by ANOVA followed by Tukey's post-hoc tests (P=<0.0001<0.05).

TABLE (3) Translucency parameter results (TP) for both groups before and after immersion in acidic beverage solutions

Variable		Treatment solution			ANOVA test
		Baseline	Coffee	Cola	P value
IPS e.max CAD	Mean±SD	18.53^{A}±1.245	12.2^{B}±0.887	13.09^{B}±1.634	<0.0001*
	95% CI (low-high)	17.72-19.35	11.62-12.78	12.03-14.16	
	Change %	-----	34.16%	29.35%	
Vita Enamic	Mean±SD	17.839^{A}±0.871	14.297^{C}±0.221	15.78^{B}±2.067	<0.0001*
	95% CI (low-high)	17.27-18.408	14.152-14.442	14.429-17.13	
	Change %	-----	19.86%	11.55%	
t-test	P value	0.0611 ns	<0.0001*	0.0075*	

Different superscript letters in the same row indicating statistically significant difference between subgroups (p< 0.05)

CI; confidence intervals *; significant (p < 0.05) ns; non-significant (p>0.05)

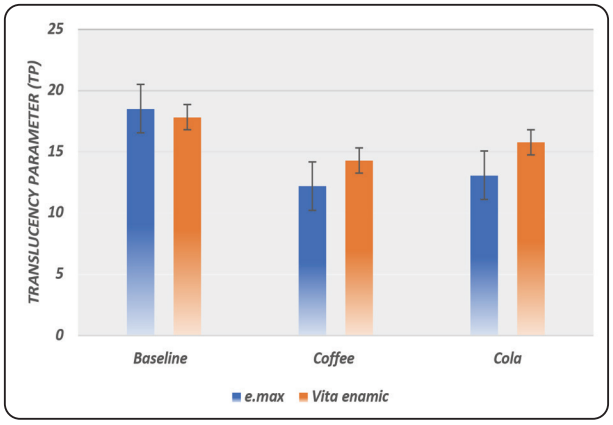

Fig. (5) Column chart of the mean values of translucency parameter for both groups before and after immersion in acidic beverage solutions

- ***Effect of the two CAD/CAM materials,*** regardless to the acidic beverage solution it was found that the differences between groups were statistically significant as discovered by two-way ANOVA test (p=0.00124 < 0.05) where (Vita Enamic > IPS e.max CAD).
- ***Effect of the two acidic beverage solutions,*** irrespective of the group it was found that immersion solutions had a significant effect on mean values as revealed by two-way ANOVA test (p=<0.0001< 0.05) where (non-immersed > Coca-Cola > Coffee).

III. iii. Vickers hardness (HV):

Vickers hardness (HV) results (Mean±SD) for both groups before (baseline) and after immersion in acidic beverage solutions are displayed numerically in Table (4) and graphically in Figure (6) as follows.

For Group I: IPS e.max CAD, it was found that the highest mean ± SD values of Vickers hardness were recorded before (baseline) immersion subgroup (345.58±7.49 Kgf/mm^2) followed by Coffee subgroup mean ± SD values (300.61±0.87 Kgf/mm^2) meanwhile the lowest mean ± SD values were recorded with Coca-Cola subgroup (294.18±0.91 Kgf/mm^2). The difference among subgroups was statistically significant as indicated by ANOVA test followed by Tukey's post-hoc pair-wise tests (P=<0.0001<0.05).

For Group II: Vita Enamic, it was found that the highest mean ± SD values of Vickers hardness were recorded before (baseline) immersion subgroup (254.38±13.71 Kgf/mm^2) followed by Coffee subgroup mean ± SD values (223.68±2.26 Kgf/mm^2) meanwhile the lowest mean ± SD values were recorded with Coca-Cola subgroup (221.65±2.71 Kgf/mm^2). The difference between groups was statistically significant as proven by ANOVA test (P=<0.0001<0.05). Tukey's post-hoc pair-wise tests showed non-significant (p > 0.05) difference between (Coffee and Coca-Cola) subgroups.

TABLE (4) Vickers hardness results (Kgf/mm^2) for both groups before and after immersion in acidic beverage solutions

Variable		Treatment solution			ANOVA test
		Baseline	Coffee	Cola	P value
IPS e.max CAD	Mean±SD	345.58^A±7.49	300.61^B±0.87	294.18^C±0.91	<0.0001*
	95% CI (low-high)	340.68 - 350.48	300.04 - 301.19	293.59 - 294.77	
	Change %	-----	13.01 %	14.87 %	
Vita Enamic	Mean±SD	254.38^A±13.71	223.68^B±2.26	221.65^B±2.71	<0.0001*
	95% CI (low-high)	245.42 - 263.33	222.20 - 225.16	219.87 - 223.42	
		-----	12.07 %	12.87 %	
t-test	P value	<0.0001*	<0.0001*	<0.0001*	

Different superscript letters in the same row indicating statistically significant difference between subgroups (*p < 0.05*)
CI; confidence intervals ****; significant (p < 0.05)*** ***ns; non-significant (p>0.05)***

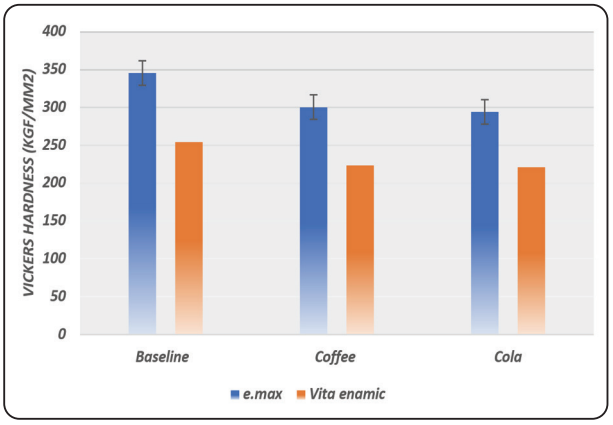

Fig. (6) Column chart of the mean values of Vickers hardness for both groups before and after immersion in acidic beverage solutions

- ***Effect of the two CAD/CAM materials***, regardless to the acidic immersion solution it was found that the differences between groups were statistically significant as revealed by two-way ANOVA test (p=<0.0001 < 0.05) where (IPS e.max CAD > Vita Enamic).
- ***Effect of the two acidic beverage solutions***, irrespective of the group it was found that the acidic beverage solutions significantly effect on mean values as confirmed by two-way ANOVA test (p=<0.0001< 0.05) where (non-immersed > Coffee > Coca-Cola). Tukey's post-hoc pair-wise tests showed non-significant (p > 0.05) difference between (Coffee and Coca-Cola) subgroups.

III. iv. Fracture toughness (MPa.m$^{1/2}$):

Fracture toughness (MPa.m$^{1/2}$) results (Mean±SD) for both groups before (baseline) and after immersion in acidic beverage solutions are shown numerically in **Table (5)** and graphically in **Figure (7)** as follows.

For Group I: IPS e.max CAD, it was found that the highest mean ± SD values of Fracture toughness were recorded in the before (baseline) immersion subgroup (4.067±0.73 MPa.m$^{1/2}$) followed by Coffee subgroup mean ± SD values (3.715±0.58 MPa.m$^{1/2}$) meanwhile the lowest mean ± SD values were recorded with Coca-Cola subgroup (3.675±0.583 MPa.m$^{1/2}$). The difference among subgroups was insignificant statistically as specified by ANOVA test tests (P=0.2586 > 0.05).

For Group II: Vita Enamic, it was found that the highest mean ± SD values of Fracture toughness were recorded in the before (baseline) immersion subgroup (3.628±0.24 MPa.m$^{1/2}$) followed by Coffee subgroup mean±SD values (3.084±0.61 MPa.m$^{1/2}$) meanwhile the lowest mean±SD values were recorded with Coca-Cola subgroup (2.928±0.52 MPa.m$^{1/2}$). The difference between groups showed statistical significance as demonstrated by ANOVA test (P=0.0005<0.05). Tukey's post-hoc pair-wise tests showed non-significant (p > 0.05) difference between (Coffee and Coca-Cola) subgroups.

TABLE (5) Fracture toughness results (MPa.m$^{1/2}$) for both groups before and after immersion in acidic beverages solutions

Variable		Treatment solution			ANOVA test
		Baseline	Coffee	Cola	P value
IPS e.max CAD	Mean±SD	4.067^{A}±0.73	3.715^{A}±0.58	3.675^{A}±0.583	0.2586 ns
	95% CI (low-high)	3.586 - 4.548	3.330 - 4.100	3.294 - 4.056	
	Change %	----	8.67%	9.65%	
Vita Enamic	Mean±SD	3.628^{A}±0.24	3.084^{B}±0.61	2.928^{B}±0.52	0.0005*
	95% CI (low-high)	3.469-3.787	2.683-3.484	2.588-3.269	
	Change %	----	15.05%	19.29%	
t-test	P value	0.0219*	0.0408*	0.0113*	

Different superscript letters in the same row indicating statistically significant difference between subgroups (p < 0.05)
CI; confidence intervals *; significant (p < 0.05) ns; non-significant (p>0.05)

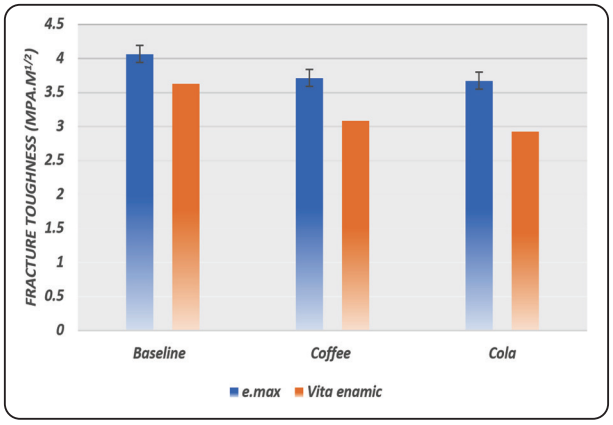

Fig. (7) Column chart of the mean values of fracture toughness for both groups before and after immersion in acidic beverages solutions

- ***Effect of the two CAD/CAM materials***, regardless to the acidic beverage solution it was found that the differences between groups were statistically significant as discovered by two-way ANOVA test ($p=0.0024 < 0.05$) where (IPS e.max CAD > Vita Enamic).
- ***Effect of the two acidic beverage solutions,*** irrespective of the group it was found that the acidic beverage solutions had a significant effect on mean values as revealed by two-way ANOVA test ($p=0.0008< 0.05$) where (non-immersed > Coffee > Coca Cola). Tukey's post-hoc pair-wise tests showed non-significant ($p>0.05$) difference between (Coffee and Coca Cola) subgroups.

DISCUSSION

Creating restorations that have the appearance of the natural tooth is one of the crucial obstacles in dental practice[2,43]. Nowadays, there has been a paradigm shift towards using machinable esthetic materials with the increased popularity of CAD/CAM systems. Clinical success of restorations not only relies upon mechanical and physical properties, but on the esthetic appearance as well[44]. Therefore, amongst a wide range of materials available, IPS e.max CAD and Vita Enamic were nominated for this study as they are of the most that provide enhanced esthetic qualities.

The oral environment is considered as a multiplex hydrous medium with fluctuating pH, that has been reported to adversely affect the mechanical behavior and esthetic properties and of different restorations while in service due to the continuous consumption of acidic beverages and food[44]. Moreover, owing to the high potential for staining in caffeine containing beverages[45], Coffee (recording a pH 5.8, and considered as a weak acid) consisting of caffeine, tannic acid, citric acid, chlorogenic acid and Coca-Cola (recording a pH 2.49 and mentioned to be a powerful acid) containing phosphoric acid, carbonated water, sugar, and caramel color [46,47] were chosen for our study as being the most frequently used acidic beverages among personages and the effects of immersion in coffee and cola are considered to be a reliable measure to estimate the materials' affinity to discolor.

Upon exposure of ceramics in the oral environment to such acidic beverages, degradation of ceramics may occur, leading to increased surface roughness, alteration of surface hardness, causing wear of the opposing dentition or restorations. Else more, reduction in the strength, accompanied with change in the color of the restoration, could be detected which in return negatively affects their clinical service[48,49] resulting in patient dissatisfaction with the restorations[50].

Therefore, this study aimed to assess the effect of two acidic beverages (Coffee, and Coca-Cola) on translucency, microhardness, and fracture toughness of two CAD/CAM aesthetic materials namely, IPS e.max CAD, Vita Enamic.

Being an in-vitro study, allowed a governed stereotype method of fabrication to provide consistent information regarding the material behavior towards the tested beverage solutions. For both IPS e.max CAD and Vita Enamic, using the isoMet 4000 microsaw, samples were sectioned to a thickness of one mm, and were verified using a digital caliper to

exclude any inconstant factors that could affect the results of color change and surface microhardness[50].

Several research have intensified the influence of the surface finishing procedures and polishing materials on the color instability and surface irregularities of the restorative esthetic materials. Hence, prior to any testing procedures, all samples for both materials were finished and polished by the same technician following their manufacturer's instructions to attain a highly smooth flat surface, to ensure reliability of the measurements [51-54].

This study measured the change in color and translucency, surface microhardness and fracture toughness 3 weeks afterwards of submerging in Coffee and Coca-Cola. It has been attested in the literature that one week of immersion in a laboratory is equivalent to seven months of drinking a single cup of Coffee and Coca-Cola daily. In the present study, immersion for 3 weeks, which was equal to 21 months of using up such beverages in a clinical situation [36,55,56]. To simulate the neutralizing effect of saliva intra-orally, specimens were submerged for 24 hours in artificial saliva prior to immersion in beverage solutions[57].

After baseline readings, coffee solution was prepared then strained using a filter paper to remove any residues[58]. Coffee solutions were renewed daily to avoid yeast fermentation of coffee[46,59]. Regarding Coca-Cola solution they were also changed daily on regular basis to dispense a freshly mixed solution. As recommended by El-Sayed etal[57], all samples were incubated at 37º C to maintain and simulate the ideal temperature of the oral cavity throughout the research.

Although, the values of the color change (ΔE) are considered the point of reference for measurement analysis, but in this value, only the (L*, a*, b*) CIELab coordinates are considered without other criteria such as translucency, opalescence, fluorescence, brightness[2,38,60] being evaluated. Thus, for a more intense chrome analysis of the material, this present study measured the translucency parameter (TP) after immersion of samples of both groups in Coffee and Coca-Cola beverage solutions.

Referring to the outcomes of this investigation, the first null hypothesis was rejected, as results revealed a significant change in the color of restorative materials after immersion in the two acidic solutions with a remarkable decrease in the translucency parameter (TP). For both IPS e.max and Vita Enamic groups the TP values declined significantly from the baseline before immersion, followed by the Coca-Cola subgroup, ending by the least TP value with the coffee subgroup, with a non-significant difference between coffee and Coca-Cola subgroups for the IPS e.max samples, while Vita Enamic exhibited a significant difference between the two subgroups. (Table 3, Figure5). These findings could be explained on the basis that, despite having a lower pH value than Coffee, the amount of color change and decrease in the TP value for the Coca-Cola subgroup was less than that for coffee subgroup, mostly due to the little percent of yellow colorant in its composition than that of coffee[61]. Furthermore, the Coca-Cola contains carbonic and phosphoric acids in its composition, which causes deterioration to the inherent surface condition of the ceramic as a result, a surface disintegration occurs leading to the separation of the silica in its composition and in the loss of alkaline ions [62].This may lead to diffusion of pigments and, consequently, discoloration of the material[61]. Therefore, the optical changes observed within IPS e.max CAD group were not an internal color change of the ceramic but a result of its surface degeneration and external color additions. On the other hand, Coffee contains yellow pigments that possess a low affinity, which leads to discoloration of the material caused by adsorption and absorption of colorants[61,63] resulting in a lower translucency of the ceramic. Results were found to be coinciding with those of dos Santos et al[64]. While, for the Vita Enamic (PICN) group the findings of this study agreed with Trussi and co-authors[65] and Borges et al[66], who reported that exposures to acidic beverages might cause decomposition of methacrylate ester

bonds leading to disintegration of the polymer matrix of resin composites, leaving the material more liable to discoloration that will in return affect its translucency.

Important mechanical factors as hardness and fracture toughness play a role in the clinical durability of restorations especially in stress bearing areas[67]. The surface microhardness of the material indicates how hard the material is to resist scratching or penetration. The high-rise in microhardness of a material, then the mechanical properties are believed to be higher. Within this research, to assess the hardness of the CAD/CAM materials under investigation Vickers microhardness test was used[32].

Again, from the present outcomes, it was disagreed with the second null hypothesis. For IPS e.max CAD material, statistically significant differences in Vickers Hardness values (HV) were found, with the highest values before immersion in the acidic beverage's solution at the baseline, followed by those after immersion in coffee and the least values were exhibited with the Coca-Cola subgroup again with a significant difference between both subgroups. Whereas for the Vita Enamic material another significant difference was found, with the highest values at the baseline, followed by the coffee subgroup, to end finally with least values in the Coca-Cola subgroup with an insignificant difference between the tested subgroups. (Table 4, Figure 6)

One of the most frequent types of failure of dental restorations in clinical practice is fracture[33]. Since fracture toughness which is defined as the material's resistance to crack propagation has become one of the reliable mechanical properties to be measured as it reflects how the material might behave in the clinical situation[34]. Consequently, within our study, Vickers micro-indentations were used to measure fracture toughness [68,69]. In this approach, fracture toughness was calculated by measuring the resulted cracks from an indented surface at the fracture site[70].

Once more, based on our results, the third null hypothesis was also rejected. There was a statistically significant difference in the fracture toughness of both CAD/CAM materials tested, with the highest values recorded at the baseline before immersion, followed by the coffee subgroup and the lowest values were for the Coca-Cola subgroups. Moreover, regardless to the acidic beverage solution, both groups showed a statistically significant difference and irrespective of the groups tested, there was a non-significant difference between both sub groups (Coffee and Coca-Cola) (Table 5, Figure 7)

As an explanation to the findings of this work, for the IPS e.max group, microhardness declined significantly following the immersion in acidic beverage solutions and this could be attributed to the fact that disturbance to the silica phase of lithium disilicate secondary to acidic exposures might cause release of alkaline ions such as Al, Si, and Zr [71,] while, for the Vita Enamic group, exposure to acidic beverages had a degrading effect to the interface between inorganic fillers and organic resin matrix leading to material dissolution and accordingly, microhardness diminished obviously [72]. Nevertheless, acids might increase the water sorption of the material making the resin matrix growing larger and creating spaces between the particles. This could result in washing away of the inorganic fillers and overall disintegration of the material causing surface roughness which consequently decreases surface microhardness and apparently fracture toughness[73,74].

Last but not the least, this study was an in-vitro design trying to resemble the acidic vulnerability intra-orally. This resemblance may not precisely express the oral environment in certain conditions as when the intensity of an acid could be diminished due to the buffering extent of saliva, duration, and frequency of exposure, and some of the oral hygiene measures the patient may follow that could minimize the deleterious effect of acidic beverages consumed. Subjecting such materials to thermocycling, mimicking the laboratory conditions of the oral environment is advisable in further in-vitro studies. Therefore, the results of this study are only applicable to the same conditions.

RECOMMENDATIONS

Since it was an in vitro study, further long-term clinical assessments are essential for proper evaluation of the optical behavior of CAD-CAM materials and their survival in different acidic media.

Patients having such esthetic tooth-colored restorations should avoid unnecessary consumption of coffee and Coca-Cola to lessen stainability of the material and diminish the change in the optical qualities of the materials.

CONCLUSIONS

Within the limitations of this study, the following conclusions could be drawn:

1. Coffee and Coca-Cola beverages can adversely affect the translucency of glass-ceramic materials.
2. Hybrid ceramics are susceptible to changes in translucency after being subjected to acidic beverages.
3. Microhardness and fracture toughness of different CAD/CAM esthetic materials was negatively affected secondary to exposure to beverages with low pH values.

REFERENCES

1. Zafar MS, Amin F, Fareed MA, Ghabbani H, Riaz S, Khurshid Z, et al. Biomimetic aspects of restorative dentistry biomaterials. Biomimetics. 2020;5:34.
2. Nogueira AD, Della Bona A. The effect of a coupling medium on color and translucency of CAD CAM ceramics. J Dent 2013;41: e18-23.
3. 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: 456-61
4. Culp L, McLaren EA. Lithium disilicate: the restorative material of multiple options. Compend Contin Educ Dent 2010;31. 716-20;722,724-5.
5. Gehrt, Maren, ***et al***. Clinical results of lithium-disilicate crowns after up to 9 years of service. Clinical Oral Investigations; 2013.17(1):275-284
6. Coldea A, Swain MV, Thiel N. Mechanical properties of polymer-infiltrated-ceramic-network materials. Dent Mater. 2013; 29: 419-26.
7. Lauvahutanon S, Takahashi H, Shiozawa M, Iwasaki N, Asakawa Y, Oki M, et al. Mechanical properties of composite resin blocks for CAD/CAM. Dent Mater J. 2014; 33: 705–10.
8. Gracis, Stefano, ***et al***. A new classification system for all-ceramic and ceramic-like restorative materials. International Journal of prosthodontics; 2015; 28(3): 227-235.
9. **Watts A, Addy M**. Tooth discoloration and staining: a review of the literature. Br Dent J. 2001;190:309-16.
10. B. Kukiattrakoon, C. Hengtrakool, and U. Kedjarune-Leggat, "Elemental release and surface changes of fluorapatite-leucite porcelain upon immersion in acidic agents," Journal of Dental Sciences, 2010; vol. 5, no. 4, pp. 189–200.
11. L. Fu, H. Engqvist, and W. Xia, "Glass-ceramics in Dentistry: a review," Materials, 2020, vol. 13, no. 5, p. 1049
12. M. Alnasser, M. Finkelman, A. Papathanasiou, M. Suzuki, R. Ghaffari, and A. Ali, "Effect of acidic pH on surface roughness of esthetic dental materials," J Prosthet. Dent, 2019 vol. 122, no. 6, pp. 567–e8.
13. Stawarczyk B, Sener B, Trottmann A, Roos M, Ozcan M, Hammerle CH. Discoloration of manually fabricated resins and industrially fabricated CAD/CAM blocks versus glass- ceramic: effect of storage media, duration, and subsequent polishing. Dental Materials Journal. 2012; 31:377-83.
14. Arocha MA, Mayoral JR, Lefever D, Mercade M, Basilio J, Roig M. Color stability of siloranes versus methacrylate-based composites after immersion in staining solutions. Clinical Oral Investigations. 2013;17:1481-7.
15. Ardu S, Gutemberg D, Krejci I, Feilzer AJ, Di Bella E, Dietschi D. Influence of water sorption on resin composite color and color variation amongst various composite brands with identical shade code: an in vitro evaluation. J. Dent. 2011; 39: e37-44.
16. Assunção WG, Barão VA, Pita MS, Goiato MC. Effect of polymerization methods and thermal cycling on color stability of acrylic resin denture teeth. J Prosthet Dent 2009;102:385-92.
17. Anusavice KJ, Shen C, Rawls HR. Phillips' science of dental materials. 12th ed. St. Louis: Elsevier; 2012. p. 38.
18. Ergun G, Mutlu-Sagesen L, Ozkan Y, Demirel E. In vitro color stability of provisional crown and bridge restoration materials. Dent Mater J 2005;24:342-50.

19. Turgut S, Bagis B. Colour stability of laminate veneers: an in vitro study.J Dent 2011;39:e57-64
20. Hipólito AC, Barão VA, Faverani LP, Ferreira MB, Assunção WG. Color degradation of acrylic resin denture teeth as a function of liquid diet: ultraviolet-visible reflection analysis. J Biomed Opt 2013;18:105005.
21. Bagis B, Turgut S. Optical properties of current ceramics systems for laminate veneers. J Dent 2013;41:e24-30.
22. Della Bona A. Bonding to ceramics: scientific evidences for clinical dentistry. 1st ed. Sao Paulo: Artes Médicas; 2009. p. 91-132.
23. Li Q, Yu H, Wang YN. Spectrophotometric evaluation of the optical influence of core build-up composites on all-ceramic materials. Dent Mater 2009;25:158-65.
24. Yu B, Ahn J-S, Lee Y-K. Measurement of translucency of tooth enamel and dentin. Acta Odontol Scand 2009;67:57-64.
25. Jeong ID, Bae SY, Kim DY, Kim JH, Kim WC. Translucency of zirconia-based pressable ceramics with different core and veneer thicknesses. J Prosthet Dent 2016;115:768-72.
26. Sallam HI, Eldwakhly E. Translucency and biaxial flexural strength of Monolithic zirconia as affected by sintering speeds EDJ: 2017; Vol. 63, 861:877
27. Johnston WM, Ma T, Kienle BH. Translucency parameter of colorants for maxillofacial prostheses. Int J Prosthodont 1995;8:79-86.
28. Hu X, Johnston WM. Translucency estimation for thick pigmented maxillofacial elastomer. J Dent 2011;39:e2-8
29. Colombo, M.; Poggio, C.; Lasagna, A.; Chiesa, M.; Scribante, A. Vickers Micro-Hardness of New Restorative CAD/CAM Dental Materials: Evaluation and Comparison after Exposure to Acidic Drink. Materials 2019, 12, 1246. [CrossRef]
30. Hengtrakool, C.; Kukiattrakoon, B.; Kedjarune-Leggat, U. Effect of Naturally Acidic Agents on Microhardness and Surface Micromorphology of Restorative Materials. Eur. J. Dent. 2011, 5, 89–100. [CrossRef]
31. Prabhakar, A.R.; Paul, M.J.; Basappa, N. Comparative Evaluation of the Remineralizing Effects and Surface Micro Hardness of Glass Ionomer Cements Containing Bioactive Glass (S53p4):An In Vitro Study. Int. J. Clin. Pediatr. Dent. 2010, 3, 69–77. [CrossRef] [PubMed]
32. Arýsu, H.D.; Dalkilic, E.E.; Alkan, F.; Erol, S.; Uctasli, M.B.; Cebi, A. Use of Artificial Neural Network in Determination of Shade, Light Curing Unit, and Composite Parameters' Effect on Bottom/Top Vickers Hardness Ratio of Composites. Biomed. Res. Int. 2018, 2018, 4856707.
33. Van Nieuwenhuysen JP, D'Hoore W, Carvalho J, Qvist V. Long-term evaluation of extensive restorations in permanent teeth. J Dent. 2003;31:395–405.
34. Scherrer SS, Kelly JR, Quinn GD, Xu K. Fracture toughness (KIc) of a dental porcelain determined by fractographic analysis. Dent Mater.1999;15:342–8.
35. Alsilani RS, Sherif M, Elkhodary NA. Evaluation of colour stability and surface roughness of three CAD/CAM materials (IPS e.max, Vita Enamic, and PEEK) after immersion in two beverage solutions:An in vitro study. International Journal of Applied Dental Sciences 2022; 8(1): 439-449
36. Lauvahutanon S, Iwasaki N, Oki M, Finger WJ. "Discoloration of Various CAD/CAM Blocks after Immersion in Coffee" Restorative Dental Endodontic Journal. 2017;42(1):9-18.
37. Johnston WM. Color measurement in dentistry. J Dent 2009;37 Suppl 1:e2-6.
38. Ozturk, O., B. Uludag, A. Usumez, V. Sahin, and G. Celik. The effect of ceramic thickness and number of firings on the color of two all-ceramic systems." J. Prosthet Dent 2008.100: 99-106.
39. Evans AG, Charles EA: Fracture toughness determinations by indentation. J Am Ceram Soc 1976;59:371-372
40. Anstis GR, Chantikul P, Lawn BR, et al: A critical evaluation of indentation techniques for measuring fracture toughness: I.Direct crack measurements. J Am Ceram Soc 1981;64:533-538
41. Seghi RR, Denry IL, Rosenstiel SF: Relative fracture toughness and hardness of new dental ceramics. J Prosthet Dent 1995;74:145-150
42. Scherrer SS, Denry IL, Wiskott HW, et al: Effect of water exposure on the fracture toughness and flexure strength of a dental glass. Dent Mater 2001;17:367-371
43. Brewer JD, Wee A, Seghi R. Advances in color matching. Dent Clin North Am 2004;48:341-58
44. Della Bona A, Kelly JR. The clinical success of all-ceramic restorations. J Am Dent Assoc. 2008;139:8S-13S.
45. Kim JH, Lee YK, Powers M. Influence of a series of organic and chemical substances on the translucency of resin composites. Journal of Biomedical Material Research Part B: Applied Biomaterials. 2006;77:21-7
46. Arocha MA, Basilio J, Llopis J, Bella ED, Roig M, Ardu S, et al. "Colour Stainability of Indirect CAD – CAM Processed Composites vs. Conventionally Laboratory Processed Composites after Immersion in Staining Solutions."J Dent. 2014;42(7):831-8. Doi:10.1016/j.jdent.2014.04.002

47. Scotti N, Ionescu A, Comba A, et al. "Influence of Low pH Beverages on the Two-Body Wear of CAD/. CAM monolithic materials" MDPI polymer Journal. 2021;13(17):2915

48. Yerliyurt K, Hayran Y. "Effect of Surface Finishing on the Colour Stability and Translucency of Dental Ceramics." BMC Oral Health. 2018;1(13):18:40. Doi:10.1186/s12903-018-0508-4

49. Vichi A, Ferrari M, Davidson CL. Color and opacity variations in three different resin-based composite products after water aging. Dent Mater. 2004;20:530-4.

50. Acar O, Yilmaz B, Altintas H, Chandrasekaran I, Johnston WM. "Color Stainability of CAD/CAM and Nanocomposite Resin Materials." J Prosthet Dent.

51. Elraggal A, Afifi R , Elraggal IA: Effect of erosive media on microhardness and fracture toughness of CAD-CAM dental materials: BMC Oral Health (2022) 22:191 https://doi.org/10.1186/s12903-022-02230-1

52. Sonmez N, Gultekin P , Turp V, Akgungor G, Sen D and Mijiritsky E Evaluation of five CAD/CAM materials by microstructural characterization and mechanical tests: a comparative in vitro study BMC Oral Health (2018) 18:5 DOI 10.1186/s12903-017-0458-2

53. Alghamdi WS, Labban N, Maawadh A, Alsayed HD, Alshehri H, Alrahlah A, Alnafaiy SM. Influence of Acidic Environment on the Hardness, Surface Roughness and Wear Ability of CAD/CAM Resin-Matrix Ceramics Materials 2022, 15, 6146. https://doi.org/10.3390/ma15176146

54. Omar NM, Mohammed HR, Hagag KM. Effect of various ph media on fracture toughness and hardness of bi-layered reinforced polymer and monolithic hybrid ceramics A.J.D.S. 2020; Vol. 23- No. 2- 103:109

55. Seyidaliyeva A, Dipl.-ing SR, Evagorou Z, Hassel AJ, Rammelsberg P, Zenthöfer A. "Color Stability of Polymer-Infiltrated-Ceramics Compared with Lithium Disilicate Ceramics and Composite," J Esthet Restor Dent. 2020;32:43-50. Doi:10.1111/jerd.12525

56. Shiozawa M, Takahashi H, Asakawa Y, Iwasaki N. Color stability of adhesive resin cements after immersion in coffee. Clin Oral Investig. 2015;19:309-17.

57. El-Sayed SM, Basheer RR, Bahgat SF. "Color stability and fracture resistance of laminate veneers using different restorative materials and techniques." EDJ 2016;62(1):1-15.

58. Fahmy AR, Zohdy MM, Abd G, Fattah E. "Color Reproduction of Peek Material Veneered With IpsThicknesses E. Max and Visio. Lign and Composite Blocks with Different thicknesses. 2020;23(1):87-94. Doi: 10.21608/AJDSM.2020.120355

59. Eldwakhly E, Ragaai D, Ahmed M, Soliman M, Abbas MM, Badrawy W. "Color and Translucency Stability of Novel Restorative CAD/CAM Materials" Dental Medical Problem Journal. 2019;56(4):349-356. Doi:10.17219/dmp/11140

60. Ren YF, Feng L, Serban D, Malmstrom HS. Effects of common beverage colorants on color stability of dental composite resins: the utility of a thermocycling stain challenge model in vitro. J Dent 2012;40:48-56

61. Bagheri R, Burrow MF, Tyas M. Influence of food-simulating solutions and surface finish on susceptibility to staining of aesthetic restorative materials. J Dent 2005;33:389-98.

62. Ccahuana VZ, Ozcan M, Mesquita AM, Nishioka RS, Kimpara ET, Bottino MA. Surface degradation of glass ceramics after exposure to acidulated phosphate fluoride. J Appl Oral Sci 2010;18:155-65.

63. Fujita M, Kawakami S, Noda M, Sano H. Color change of newly developed esthetic restorative material immersed in food-simulating solutions. Dent Mater J 2006;25:352-9.

64. 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

65. Turssi CP, Hara AT, De Magalhães CS, Campos Serra M, Rodrigues AL. Influence of storage regime prior to abrasion on surface topography of restorative materials. J Biomed Mater Res Part B Appl Biomater. 2003;65B:227–32.

66. Borges MG, Soares CJ, Maia TS, Bicalho AA, Barbosa TP, Costa HL, et al. Effect of acidic drinks on shade matching, surface topography, and mechanical properties of conventional and bulk-fill composite resins. J Prosthet Dent. 2019;121:868.e1-868.e8.

67. Taira M, Nomura Y, Wakasa K, Yamaki M, Matsui A. Studies on fracture toughness of dental ceramics. Journal of oral rehabilitation. 1990;17(6):551-63.

68. Swab JJ, Quinn GD. Effect of precrack "Halos" on fracture toughness determined by the surface crack in flexure method. J Am Ceram Soc. 1998;81:2261–8.

69. Quinn GD, Swab JJ. Fractography and estimates of fracture origin size from fracture mechanics. Ceram Eng Sci Proc. 1995;17:51–9.

70. C1421-99 CA. Standard test method for the determination of fracture toughness of advanced ceramics at ambient

temperatures. Annu B Stand ASTM, West Conshohoken, PA, 1999

71. Alencar-Silva FJ, Barreto JO, Negreiros WA, Silva PGB, Pinto-Fiamengui LMS, Regis RR. Effect of beverage solutions and toothbrushing on the surface roughness, microhardness, and color stainability of a vitreous CAD-CAM lithium disilicate ceramic. J Prosthet Dent. 2019;121:711. e1-711.e6.

72. [a]en N, Tuncelli B, Göller G. Surface deterioration of monolithic CAD/CAM restorative materials after artificial abrasive toothbrushing. J Adv Prosthodont. 2018; 10: 271–8.

73. Rahim TNAT, Mohamad D, Md Akil H, Ab RI. Water sorption characteristics of restorative dental composites immersed in acidic drinks. Dent Mater. 2012;28:e63–70.

74. Örtengren U, Andersson F, Elgh U, Terselius B, Karlsson S. Influence of pH and storage time on the sorption and solubility behaviour of three composite resin materials. J Dent. 2001;29:35–41.