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Effect of different beverages on the color stability and microhardness of CAD/CAM hybrid versus feldspathic ceramic blocks: An in-vitro study

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Red wine

Abstract

Purpose: Aim of the present investigation is to study and compare effects of common beverages on color stability and microhardness of CAD/CAM hybrid versus feldspathic ceramic blocks.

Materials and methods: Two commercially-available CAD/CAM ceramic-blocks: Hybrid (Vita Enamic, En) and Feldspathic (Vitablocs MarkII, Vm) were selected for this study. Total of 18 specimens of each material were prepared. Baseline measurements for color and microhardness were taken using spectrophotometer and Vickers microhardness tester respectively. Specimens of each material were divided into 3 groups according to immersion medium; coffee, red wine or distilled water (control). Final measurements were taken after 28-days of immersion. Color change and percentage microhardness change were calculated. Specimens of each material were statistically analyzed using one-way-analysis-of-variance; (P < 0.05).

Results: Color measurements revealed that immersion in either coffee or distilled water resulted in significantly higher color change values for En compared to Vm. Following immersion in wine, no significant difference in color change existed between both materials. A significant reduction in microhardness of both En and Vm was revealed following immersion in coffee. This change was not significantly different between the two materials. Microhardness values of En measured before or after immersion in different solutions were significantly lower than those of Vm. After immersion in different beverages, a significant negative correlation existed between color change and percentage microhardness change for both materials.

Conclusions: Coffee may adversely affect color and microhardness of En and Vm which may consequently compromise esthetics. Different immersion media; with different polarity, may affect hardness of PICN and feldspathic CAD/CAM blocks differently.

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1. Introduction

Clinically, the success of any restorative material is directly related to its long-term continuousness; a quality which is strongly influenced by both the intrinsic characteristics of the materials, and the environment to which they are exposed. The oral cavity is a complex, aqueous environment where the restorative material is in contact with saliva and is subjected to fluctuations in pH due to consumption of different foods and beverages. Such factors have been reported to influence the esthetic and mechanical properties of the restoration while in service [1].

Over the years, the CAD/CAM esthetic materials used in dentistry have witnessed dramatic improvement. Although ceramic blocks have good mechanical properties in terms of strength and stiffness, excellent esthetics and biocompatibility, they are brittle, have low fracture toughness and are difficult to machine. Moreover, restorations may cause wear of the opposing natural teeth [2,3].

On the contrary, resin composite blocks have a low brittleness
index; thus better machinability, and the fabricated restorations cause lower wear to opposing teeth [2]. However, most resin-based restorations experience color changes upon exposure to different food and beverages [4,5]. Such color change occurs as a result of either intrinsic and/or extrinsic factors. Intrinsic factors have been attributed to alteration within the resin matrix itself. Extrinsic factors include adsorption or absorption of extrinsic stains as a result of exposure to stain-producing beverages and colored solutions, dietary and smoking habits as well as poor oral hygiene [4,6].

In an attempt to combine the merits of both resinous and ceramic materials, Vita Zahnfabrik introduced VITA ENAMIC; a hybrid dental ceramic with a dual-network structure, where the dominant porous sintered feldspathic ceramic network is strengthened by a methacrylate polymeric ceramic network, forming the so-called double network hybrid (DNH) [2,3,7] or the polymer-infiltrated-ceramic-network (PICN) [8]. Due to their fine ceramic structure and the polymer network, VITA ENAMIC was reported to have high flexural strength values [7], an elasticity close to dentin [3], and the ability to acquire high strength after adhesive bonding and therefore, minimal invasive restorations are possible [7]. In addition, previous studies documented that VITA ENAMIC had better internal and marginal adaptation than feldspathic ceramics [9]. In terms of color matching, VITA ENAMIC offers material properties that are almost identical to those of natural teeth [7].

Color change may be assessed using spectrophotometers and colorimeters. Instrumental measurement; whether in-vitro or in-vivo, eliminates the individual variation in visual color comparisons and has made it possible to study the different variables that may affect color stability. The Commission Internationale de l’Eclairage (CIE) L*a*b* is a color system that is related to the color perception of the human eye. It is nearly a uniform color space with coordinates for lightness: white-black (L*), red-green (a*), and yellow-blue (b*). Color change (ΔE) is a mathematical expression of the amount of difference between the L*a*b* coordinates of different specimens or the same specimen at different instances.

It is a well-known fact that microhardness of a material is well correlated with its compressive strength and resistance to intra-oral softening. The microhardness of a resinous material has also been reported to be detrimentally affected by the lengthy contact time with coffee, tea, mouthwashes, acidic food and low pH drinks. Such softening might worsen its wear resistance and could lead to restoration failure due to fatigue [1,10].

The increased consumption of coffee and alcoholic beverages has raised questions about their effects on the clinical performance of polymer-infiltrated-ceramic-network (PICN) restorative materials in terms of color stainability and surface hardness. Despite the widespread use of VITA ENAMIC in inlays, onlays, etc., to our knowledge, no information is available regarding their color stability. The null hypothesis of the current study was that after storage in either coffee or red wine, the color stability and microhardness of Vita Enamic are not significantly different from those of Vitabloc Mark II.

2. Materials and methods

2.1. Ceramic materials

Two commercially available CAD/CAM ceramic materials; supplied by the same manufacturer (Vita Zahnfabrik, Bad Sackingen, Germany), were used in the present investigation: a polymer-infiltrated-ceramic-network (Vita Enamic) and a feldspathic ceramic (Vitablocs Mark II) (see Table 1).

3. Methods

3.1. Specimens’ preparation

The CAD/CAM blocks of each material were sectioned using a slow speed diamond saw (Buehler, IL, USA) under copious water irrigation. Eighteen specimens of each material; 2 mm in thickness, were prepared for both color change and microhardness evaluation.

3.2. Immersion and storage of specimens

The specimens of each material (n = 18) were randomly divided into three groups (n = 6) according to the immersion solution: Coffee (C) (Nescafe Classic, Nestle Suisse SA, Vevey, Switzerland), Red wine (W) (Omar El Khayam, Egypt) and distilled water (D) as the control. For standardization, the coffee was prepared by mixing 1 g of powder with 10 ml of distilled water. Before immersion, baseline color measurements and surface microhardness were recorded for all the specimens. Subsequently, each specimen was immersed separately in a closed individual vial containing 5 ml of the immersion solution. The vials were stored in an incubator at 37 °C for 28 days. In order to avoid bacteria or yeast contamination, each specimen was rinsed with distilled water and immersed in a fresh solution every 48 h. By the end of the 28 day immersion period, specimens were taken out of their vials, rinsed with distilled water and wiped with gauze. Color and surface microhardness were then re-measured [11–15].

3.3. Color change measurements

Color measurements of all specimens, both baseline and after 28 days of immersion, were performed by the same operator using a spectrophotometer (UV-Shimadzu 3101 PC-Spectrophotometer, Japan) Color change was measured according to the (CIE) L*a*b* color scale. Measurements were carried out at wavelengths ranging from 380 to 780 nm at 10 nm intervals. A 2-degree observer function was used with CIE illuminant D65. Measurements were carried out over a black standard tile (CIE) (L* = 11.24, a* = 0.17, b* = 0.52).

Table 1

<table>
<thead>
<tr>
<th>Lot Number</th>
<th>Block dimensions</th>
<th>Manufacturer</th>
<th>Composition</th>
<th>CAD/CAM ceramic block</th>
</tr>
</thead>
<tbody>
<tr>
<td>48720</td>
<td>114 (12 x 14 x 18)</td>
<td>Vita Zahnfabrik, Bad Sackingen, Germany</td>
<td>Fine-structure feldspar ceramic 86 wt%, Methacrylate polymer 14 wt% (TEGDMA 33 wt%, UDMA 66 wt%)</td>
<td>VITA ENAMIC (En) (Polymer-infiltrated-ceramic-Network)</td>
</tr>
<tr>
<td>31710</td>
<td>114 (12 x 14 x 18)</td>
<td>Vita Zahnfabrik, Bad Sackingen, Germany</td>
<td>Fine-particle feldspar ceramic mill block, Al2O3 - SiO2 - Na2O - K2O</td>
<td>Vitablocs Mark II (Vn) (Feldspathic ceramic)</td>
</tr>
</tbody>
</table>
b* = 0.28). According to the L*, a* and b* values, the color change (ΔE) was calculated as:

$$\Delta E = \left[ ((\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2) \right]^{1/2} [12,13,16-20]$$

3.4. Microhardness measurements

Microhardness was measured using Digital Display Vickers micro-hardness tester (Model HVS-50, Laizhou Huayin Testing Instrument Co., Ltd. China). A load of 1000 g was applied smoothly, without impact, forcing the diamond indenter into the surface of each specimen. The indenter was held in place for 15 s. After the load was removed, the indentation dimensions were microscopically-recorded at 20x magnification. The two indentation diagonals were measured using a filar micrometer, to the nearest 0.1 μm and averaged. Three indentations were made on each specimen pre and post immersion (HV₁ and HVᵣ respectively). Each three readings were averaged and the hardness value (HV) was calculated by substituting in the equation $$HV = \frac{1854.4L}{d^2}$$, where L is the load in grams and d is the average diagonal in micrometers. The percentage change in hardness following immersion (HVᶜ) was calculated as:

$$HVᶜ = \frac{(HVᵣ - HV₁) \times 100}{HV₁} [8,11,16]$$

3.5. Statistical analysis

The results were statistically analyzed using SPSS 21 for Windows statistical package (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp). Descriptive statistics were presented as means, standard deviations and mean percentage changes. Analytical tests used for all parameters included (one-way analysis of variance ANOVA and Bonferroni t-test for pairwise comparison) to assess significant changes within each group and (independent t-test) to compare the two groups. Significance levels of 0.05 were used throughout all the statistical tests.

4. Results

4.1. Color change

The results of color change (ΔE) of the two investigated materials (En and Vm), after 28 days of immersion in the three immersion media (C, W and D), are shown in Table 2. After immersion in coffee or distilled water, Vita Enamic showed significantly higher color change values (4.9 ± 0.51 and 1.43 ± 0.15 respectively), compared to Vitablocs Mark II (3.83 ± 0.23 and 1.07± 0.1 respectively). The highest color change was revealed after immersion in coffee for both materials. However, no significant difference was observed between the color change values of both materials (En and Vm) after immersion in red wine (0.753 ± 0.14 and 0.797 ± 0.05 respectively).

4.2. Microhardness

Vickers hardness numbers (VHN) of the two investigated materials, before and after immersion in the three immersion media, are presented in Table 3. Before immersion, VHN of Vita Enamic (372.47 ± 23.95) was significantly lower than that of Vitablocs Mark II (550.37 ± 25.83). Similar results were obtained after immersion in coffee, red wine and distilled water for Vita Enamic (309.69 ± 9.40, 351.70 ± 12.66 and 374.70 ± 17) respectively and Vitablocs Mark II (463.76 ± 35.80, 532.31 ± 24.44 and 607.65 ± 19.25) respectively.

The percentage change in microhardness values; listed in Table 4, of both investigated materials, following immersion in the three immersion media revealed that for coffee, there was no significant difference in the percentage reduction of hardness in both materials. On the contrary, immersion in distilled water resulted in significant increase in microhardness of Vm as opposed to insignificant change in En.

### Table 2

Results of comparison of color change values (ΔE) of the two investigated materials (En and Vm) after 28 days immersion in the three immersion media (C, W and D).

<table>
<thead>
<tr>
<th>P-value</th>
<th>F-value</th>
<th>D</th>
<th>SD</th>
<th>Mean</th>
<th>W</th>
<th>SD</th>
<th>Mean</th>
<th>C</th>
<th>SD</th>
<th>Mean</th>
<th>Media</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.001*</td>
<td>272.737</td>
<td>0.151</td>
<td>1.43*</td>
<td>0.14</td>
<td>0.753</td>
<td>b</td>
<td>0.513</td>
<td>4.905*</td>
<td>En</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;0.001*</td>
<td>717.732</td>
<td>0.103</td>
<td>1.065*</td>
<td>0.0493</td>
<td>0.797</td>
<td>b</td>
<td>0.232</td>
<td>3.832*</td>
<td>Vm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.364</td>
<td></td>
<td>0.0433</td>
<td>-1.073</td>
<td></td>
<td></td>
<td></td>
<td>t-value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-4.458</td>
<td></td>
<td>0.716</td>
<td>-4.67</td>
<td></td>
<td></td>
<td></td>
<td>P-value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.002*</td>
<td></td>
<td>0.49</td>
<td>0.001*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where SD—Standard Deviation; *: Significant difference at P < 0.05; Different small letters indicates significant difference in ΔE between different media for the same ceramic material.

### Table 3

Microhardness values (VHN) of the two investigated materials (Vm and En) before and after immersion in the three immersion media (C, W and D).

<table>
<thead>
<tr>
<th>P-value</th>
<th>F-value</th>
<th>D</th>
<th>SD</th>
<th>Mean</th>
<th>W</th>
<th>SD</th>
<th>Mean</th>
<th>C</th>
<th>SD</th>
<th>Mean</th>
<th>Before Insertion</th>
<th>Media</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.001*</td>
<td>73.944</td>
<td>19.25</td>
<td>607.65</td>
<td>24.44</td>
<td>532.306</td>
<td>a</td>
<td>35.80</td>
<td>463.756</td>
<td>25.83</td>
<td>550.367</td>
<td>a</td>
<td>Vm</td>
</tr>
<tr>
<td>&lt;0.001*</td>
<td>68.519</td>
<td>17</td>
<td>374.7*</td>
<td>12.665</td>
<td>351.7</td>
<td>a</td>
<td>9.403</td>
<td>309.689</td>
<td>23.955</td>
<td>372.467</td>
<td>a</td>
<td>En</td>
</tr>
<tr>
<td></td>
<td>232.953</td>
<td>180.606</td>
<td>154.067</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>t-value</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35.129</td>
<td>27.834</td>
<td>17.659</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>P-value</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.001*</td>
<td></td>
<td></td>
<td>&lt;0.001*</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.001*</td>
<td></td>
<td></td>
<td>&lt;0.001*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where SD—Standard Deviation; *: Significant difference at P < 0.05; Different small letters indicates significant difference in microhardness between different media for the same ceramic material.
Since the above results revealed that immersion in beverages resulted in color change as well as decrease in microhardness of both materials, Pearson correlation coefficient was calculated between the percentage microhardness change and color change. The Pearson Correlation coefficient between the D_E and the percentage microhardness change was /C0 0.838 and /C0 0.755 for En and Vm respectively (Fig. 1).

### 5. Discussion

With the ongoing development in materials for CAD/CAM blocks, PICN were developed to overcome the problems associated with both resin and ceramic block materials when solely used. The increased patient awareness led to the need not only for esthetic materials that provide close reproduction of the tooth color but also for materials which maintain such color.

The changes in color and microhardness were investigated following immersion in beverages such as coffee and red wine that are known of their abilities to stain resin-based restorative materials. Distilled water was used as the control throughout the study. It has been postulated that 24 h of staining in-vitro corresponds to approximately one month in-vivo. Therefore, an immersion period of four weeks was chosen so as to equal two and half years of clinical ageing approximately [5,22–24].

Since instrumental color measurement has the advantages of being objective and quantified, CIE lab system was used in the present study to detect minor color differences [24]. \( \Delta E \) is the numerical distance between the L*a*b* coordinates of two colors, and it represents the color change values [12,25]. It was reported that changes in color values: \( \Delta E < 1 \) were undetectable by the human eye; \( 1.0 < \Delta E < 3.3 \) was appreciated only by a skilled person and considered clinically acceptable; whereas \( \Delta E > 3.3 \) was considered easily observed and not clinically acceptable [12,19,23]. Accordingly, **both Vita blocs Mark II and Vita Enamic revealed a clinically unperceivable color change after immersion in wine (\( \Delta E = 0.797 \) and 0.753 respectively) and distilled water (\( \Delta E = 1.066 \) and 1.43 respectively). On the other hand, after immersion in coffee, both materials, Vitablocs Mark II and Vita Enamic (\( \Delta E = 3.832 \) and 4.805 respectively), revealed a clinically unacceptable change. **

Following immersion in either coffee or distilled water, Vitablocs Mark II exhibited superior color stability compared to Vita Enamic; as evident from the \( \Delta E \) values listed in Table 2. On the contrary, no change was detected between both materials after immersion in red wine. Therefore, the null hypothesis was partly rejected.

Discoloration usually occurs as a result of water sorption by the resin component of the material. The type of resin matrix plays a vital role in the color sustainability of the material. According to the manufacturer, Vita Enamic consists primarily of 66 wt % hydrophobic urethane dimethacrylate (UDMA) and 33 wt % hydrophilic triethylene glycol dimethacrylate (TEGDMA). Previous studies have shown that water uptake by Bis GMA-based resins increased from 3 to 6% as the proportion of TEGDMA was increased from 0 to 1%, respectively. Accordingly, the high wt% of TEGDMA in Vita Enamic

<table>
<thead>
<tr>
<th>Material</th>
<th>Media</th>
<th>P-value</th>
<th>F-value</th>
<th>D</th>
<th>Mean</th>
<th>SD</th>
<th>W</th>
<th>Mean</th>
<th>SD</th>
<th>C</th>
<th>Mean</th>
<th>SD</th>
<th>Difference</th>
<th>t-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>En</td>
<td>C</td>
<td>≤0.001*</td>
<td>68.865</td>
<td>3.962</td>
<td>0.618</td>
<td>0.791</td>
<td>-5.559</td>
<td>b</td>
<td>2.144</td>
<td>-16.840</td>
<td>0.791</td>
<td>0.791</td>
<td>1.066</td>
<td>0.755</td>
<td>Vm</td>
</tr>
<tr>
<td>En</td>
<td>W</td>
<td>≤0.001*</td>
<td>45.391</td>
<td>2.018</td>
<td>10.422</td>
<td>4.028</td>
<td>-3.270</td>
<td>b</td>
<td>6.171</td>
<td>-15.727</td>
<td>1.113</td>
<td>0.202</td>
<td>6.171</td>
<td>1.113</td>
<td>Difference</td>
</tr>
<tr>
<td>Vm</td>
<td>C</td>
<td>≤0.001*</td>
<td>0.232</td>
<td>9.805</td>
<td>2.289</td>
<td>1.366</td>
<td>0.417</td>
<td>0.685</td>
<td>t -value</td>
<td>0.685</td>
<td>t -value</td>
<td>0.417</td>
<td>0.685</td>
<td>En</td>
<td></td>
</tr>
</tbody>
</table>

Where SD= Standard Deviation; *: Significant difference at P < 0.05; Different small letters indicates significant difference in microhardness percentage change between different media for the same ceramic material.

![Fig. 1. A border diagram showing the correlation between microhardness percentage change and color change \( \Delta E \) for the Vm (on the left) and En (on the right) ceramics.](https://digitalcommons.aaru.edu.jo/fdj/vol3/iss2/4)
blocks may have resulted in greater water sorption which may have permitted the penetration of any hydrophobic colorant into the resin matrix. Since UDMA is more hydrophobic than Bis-GMA, it is therefore more color stable. Nevertheless, it has been reported that dimethacrylates form cross-linked networks with entrapped unreacted monomers that serve as plasticizers. Such plasticization forms a more open structure, which may facilitate additional water sorption. This may explain how the resin matrix could have contributed to the higher discoloration values obtained by Vita Enamic [5,12,16,17,19,26].

The color change values; measured following immersion in coffee, for both Vitablocs Mark II (3.83 ± 0.23) and Vita Enamic (4.90 ± 0.51) are clinically unacceptable. Discoloration by coffee could be attributed to the ingress of the yellow colorant of the coffee into the microstructure of both materials. Higher sorption values were reported in materials immersed in solutions with pH ranging from 4 to 6. Since the pH of Nescafe coffee is documented to equal 5.4, this may have caused its increased sorption contributing to higher color change [12,17]. The more discolouration observed with Vita Enamic, could be attributed to compatibility of the yellow colorant with the resin matrix. The degree of dye penetration into the resin matrix depends on the dye polarity. Since coffee is a solution of low polarity, its yellow colorant may have facilitated deeper colorant penetration into the resin matrix [5,12,17,27].

On the other hand, clinically undistinguishable color change values were obtained following immersion in red wine where no significant difference existed between Vita Enamic (0.75 ± 0.14) and Vitablocs Mark II (0.80 ± 0.05). This may be attributed to the fact that the wine dye is a more polar dye in contrast to the less polar yellow colorant of the coffee. Consequently, the dye penetration into the resin part of Vita Enamic may be more difficult. In addition, the red color of the wine is due to the presence of anthocyanin, which is a water-soluble pigment. These factors might suggest that the discolouration of the samples immersed in wine was extrinsic in nature and therefore, might have been easily removed after the specimens were rinsed with distilled water and wiped with gauze. In addition, the low pH of red wine; ranging from 3.5 to 4, may have affected the surface integrity of Vita Enamic resulting in softening of the surface. This may further explain the surface discolouration of the resin part after immersion in red wine.

Although clinically acceptable, the color change values after immersion in distilled water for Vita Enamic (1.43 ± 0.15) and Vitablocs Mark II (1.07 ± 0.10) were significantly different. This could also be attributed to the resin part confined in Vita Enamic. As shown in Table 3, Vitablocs Mark II had significantly higher microhardness values (VHN) than Vita Enamic; before and after immersion in the three immersion media. Such findings were expected owing to the composite nature of Vita Enamic as opposed to the ceramic nature of Vitablocs Mark II. As reported by the manufacturer, Vita Enamic is a hybrid ceramic material with a dual network structure, consisting of 86 wt% fine-structure feldspar ceramic and 14 wt% methacrylate polymers. Therefore, it combines the properties of both ceramic and resin materials and can hence be considered as a composite material [26].

Uniquely, the microhardness of Vitablocs Mark II increased after immersion in distilled water. This is in agreement with the findings of Fahmy et al. who reported a significant increase in the hardness values of a ceramic material after saliva storage for 3 weeks. This increase in microhardness was related to an ionic exchange through the supposedly formed Si-OH layer on the ceramic surface [28].

A strong negative correlation existed between the color stability and percentage change in microhardness for both En (−0.838) and Vm (−0.755). This was in agreement with the reported literature [24]. In the present study, distilled water and coffee affected the surface hardness of the investigated materials which may have increased their susceptibility to staining [17]. The reduction in microhardness of both materials after immersion in coffee was associated with inferior color stability i.e. more discoloration. In case of red wine, no change in hardness was revealed after immersion in red wine which inturn may be associated with its color stability [12,19]. Further studies with different aging solutions seem necessary for a better understanding of the performance of PICN. Surface texture (roughness) should be assessed as well.

6. Conclusions

Within the limitations of this study, the following could be concluded:

1. Coffee may adversely affect the color as well as the microhardness of Vita Enamic and Vitablocs Mark II which may consequently compromise esthetics.
2. Different immersion media; with different polarity, may affect microhardness of PICN and feldspathic CAD/CAM blocks differently.
3. The quantitative assessment of ceramic blocks; through standardized methodologies as those described above, can help clinicians predict the performance of these materials in-vivo in patients with different beverage-drinking habits.

Conflict of interest

The authors have no conflict of interest to disclose.

References


