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Color and translucency stability of CAD/CAM restorative materials

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Aim: This study assessed the color and translucency stability of a polymer infiltrated ceramic network (PICN) and compared it with a resin composite (RC) and a feldspathic ceramic (FEL). **Methods:** Disc-shaped samples of a PICN (Vita Enamic), a feldspathic ceramic (Vitablocks Mark II), and a resin composite (Brava block) were prepared from CAD/CAM blocks. PICN and RC surfaces were finished with a sequence of polishing discs and diamond paste. FEL samples received a glaze layer. The samples were subjected to 30-min immersions in red wine twice a day for 30 days. CIE*L*a*b** coordinates were assessed with a spectrophotometer at baseline and after 15 and 30 days of immersion. Color alteration (ΔE_{00}) and translucency parameter (TP_{00}) were calculated with CIEDE2000. Average roughness was measured before the staining procedures. Color difference and translucency data were analyzed with repeated-measures ANOVA and Tukey's tests. Roughness was analyzed with the Kruskal-Wallis test. **Results:** Roughness was similar among the experimental groups. All materials had their color alteration significantly increased from 15 to 30 days of staining. PICN reached an intermediate ΔE_{00} between FEL and RC at 15 days. PICN revealed a color alteration as high as the composite after 30 days. No statistical difference was observed regarding translucency. **Conclusion:** PICN was not as color stable as the feldspathic ceramic at the end of the study. Its color alteration was comparable to the resin composite when exposed to red wine. However, the translucency of the tested materials was stable throughout the 30-day staining.

Key Words: Color. Ceramics. Composite resins. Computer-aided design. Materials testing. Surface properties.

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Introduction

Computer-aided design and computer-aided manufacturing (CAD/CAM) technology has simplified the workflow for indirect restorations processing and enabled fabricating strong polycrystalline and glass-ceramics for dental applications. In addition to ceramics, resin composite blocks are industrially polymerized under standardized temperature and pressure parameters, which ensure their mechanical properties for CAD/CAM systems usage[1].

Dental ceramics are generally stronger and more wear-resistant than resin composites[2,3]. However, the brittleness of ceramics together with its susceptibility to slow crack growth[4,5] might result in worse fatigue behavior compared to some composites[6]. In an attempt to combine characteristics such as the resilience from resin composites and the resistance to abrasion from ceramics, a hybrid material was developed and made available as milling blocks. Vita Enamic (Vita Zahnfabrik) is a polymer-infiltrated ceramic-network (PICN) material which gathers a sintered feldspathic ceramic scaffold (86w%) filled with a polymeric network (14w%) in a fully integrated structure. This combination results in a material with elastic modulus in the range of human dentin (~30 GPa) and provides it with easy machinability. PICN can be milled more quickly than ceramics, which gives it a great advantage for chairside usage[7].

Ceramics are more esthetically stable than composites[3,8,9]. Resin composites are more susceptible to water sorption, mainly facilitated by hydrophilic compounds of its organic matrix[10]. Water sorption degrades the bonding between resin matrix and filler particles and pigments infiltrate easily in these interfaces[11]. In contrast, particle-filled glass-ceramics consists of a vitreous matrix filled with glass or crystalline particles[12], which gives it a denser microstructure and results in less discoloration. PICN is expected to present an intermediate optical behavior between composite and ceramic. However, studies comparing the color and translucency stability of PICN with other CAD/CAM materials are required to confirm this information.

Studies have evaluated the color and/or translucency stability of PICN after days of immersion in staining beverages (e.g., coffee, tea, red wine, cola, or juice) and compared it with other restorative materials[9,13-16]. These studies applied diverse staining protocols and methods for calculating the optical properties, such as CIELAB[9,14], CIEDE2000[13,15,16], translucency parameter[13,14], percentage of light transmission[9], or contrast ratio[13,16]. In addition, most of the studies perform silicon carbide paper polishing for all materials. The surfaces of the samples are finished on different grits (i.e. P4000, P1200) in each study, which might influence color stability and hinder the comparison of results. Composite, ceramics, and hybrid materials are clinically subjected to different finishing procedures prior to cementation. This should be considered for studying the optical behavior of restorative materials since it leads to more realistic results. Moreover, there is a need for studies using translucency and color calculation methods and clinical thresholds comparisons that are described in the literature as the most accurate[17,18].

Esthetic issues are one of the main cited reasons for substituting anterior composite restorations[19] and feldspathic ceramic veneers[20] in clinical follow-ups. As PICN is still a new material, there is little evidence from clinical studies[21,22] and no consensus about its clinical behavior regarding esthetic issues. Furthermore, *in vitro* studies gives us an estimation of what to expect *in vivo*. Hence, this study aimed to assess the color and translucency stability of PICN and compare it with a resin composite (RC) and a feldspathic ceramic (FEL) also available in CAD/CAM blocks. The tested hypotheses were that PICN would: 1) show intermediate color stability between the ceramic and the composite; and 2) its translucency would keep stable throughout the 30-day staining challenge.

Materials and Methods

Study design

The factors analyzed in this *in vitro* study were material (hybrid ceramic, feldspathic ceramic, or resin composite) and exposure time in the staining media (15 or 30 days). Measurements from the same sample were compared between the checkpoints (repeated measures approach). The outcomes studied were color difference (ΔE_{00}) and translucency (TP_{00}). The commercial brands, shades, and composition of the restorative materials used in this study are described in Table 1.

Table 1. Labels, material type, commercial brand, shades, and composition of each CAD/CAM material used in the study.

Label	Material	Commercial brand	Shade	Composition
PICN	Hybrid Ceramic	Vita Enamic (Vita Zahnfabrik)	1M2 T	SiO_2-Al_2O_3-Na_2O-K_2O-Br_2O_3-ZrO_2-CaO, UDMA - TEGDMA
FEL	Feldspathic Ceramic	Vita Mark II (Vita Zahnfabrik)	A2C	Al_2O_3- SiO_2- Na_2O-K_2O
RC	Resin composite	Brava Block (FGM Dental Group)	A2 HT	Methacrylate monomers, initiator, co-initiator, stabilizers, silane, glass-ceramic particles, silica, and pigments.

Sample preparation

CAD/CAM blocks of a hybrid ceramic (PICN – Vita Enamic, Vita Zahnfabrik, Bad Sackingen, Germany), a feldspathic ceramic (FEL – Vita Mark II, Vita Zahnfabrik, Bad Sackingen, Germany), and a resin composite (RC – Brava block, FGM Dental Group, Joinville, Brazil) with initial dimensions of 12 mm × 14 mm × 18 mm were used to prepare disc-shaped samples (10 mm diameter × 1.2 mm thick, n = 12). The blocks were ground into cylinders using a 100-grit SiC paper under water-cooling in a polishing machine (EcoMet 250, Buehler, Lake Bluff, USA). The cylinders were then sectioned into discs in a precision cutting machine (Isomet 1000, Buehler, Lake Bluff, USA) with a diamond blade. The PICN and RC discs had both sides ground with a 100-grit SiC paper to a thickness of 1.3 mm. The FEL discs were ground until they were 1.2 mm thick.

The top surface of PICN and RC samples were subjected to a sequence of coarse, medium, fine, and superfine polishing discs (Sof-Lex, 3M-ESPE, St. Paul, USA), and finished using a felt disc with aluminum-oxide extra fine (6 – 8 μm grit) polishing paste (Diamond Flex and Diamond R, FGM Dental Group, Joinvile, Brasil). The polishing discs and felts were placed in parallel to the samples and the polishing was performed for 20 seconds for each disc. The samples were rinsed in water between discs. The polishing procedures were performed by a trained operator using a low-speed motor associated with a contra-angle handpiece (~10,000 rpm) and light pressure. New polishing discs were used for each sample. The final thickness was 1.2 mm (± 0.05 mm).

The FEL samples received a thin glaze layer on their top surfaces (Akzent Plus, VITA Zahnfabrik, Bad Sackingen, Germany). The glaze powder was mixed with the building liquid to obtain a creamy consistency. The mix was applied over the ceramic top surface with a brush, and the samples were subsequently fired in a furnace (Vacumat 600 MP, Vita Zahnfabrik, Bad Sackingen, Germany). Glaze firing was performed according to the manufacturer's instructions (950°C, 1 min dwell time). All the samples had their thickness measured with a digital caliper after the firing process. The thicknesses ranged from 1.23 mm to 1.27 mm. The bottom surfaces (not glazed) of the ceramic samples were slightly ground with 100-grit SiC paper until 1.2 mm thick discs were obtained.

All samples (n = 12) were stored in distilled water at 37°C for 24h. Then, baseline CIE*L*a*b** measurements were taken and the top surfaces of all samples had roughness measured to ensure standardization.

Roughness measurements

The roughness measurements were taken in a contact roughness tester (Mitutoyo SJ-410, Mitutoyo) according to the ISO Standard 4287-1997. The average roughness (Ra) parameter of all samples was evaluated (n = 12). Three measurements were obtained from the polished/glazed side of each sample in both the X and Y-axis. A cut-off of lC 0.8 mm (n = 5) and a ripple filter of lS 2.5 mm was used. The mean Ra values of each sample were used in the statistical analysis.

Staining procedures

The samples were immersed in red wine (Salton Classic Cabernet Sauvignon, Vinícola Salton, Bento Gonçalves, Brazil) for 30 min at 37°C twice a day with a dwell time of 12 h between the immersions. This procedure was carried out for 30 days, totaling 30 h of immersion. After each immersion, the samples were rinsed and stored in distilled water at 37°C until the next immersion. The wine was replaced after every immersion. Red wine was chosen because it is acidic and rich in pigment, which has been demonstrated to result in high color alteration in ceramics, composites, and hybrid materials[9,14].

Color and translucency stability analyses

The CIE*L*a*b*(Comission International L´Eclairage)* parameters were assessed with a spectrophotometer (SP60, X-Rite, Grand Rapids, USA). The samples were placed over white, black, and gray backgrounds and the *L*a*b** parameters were recorded. The lightness axis (*L**) in this system ranges from 0 (black) to 100 (white), and *a** and *b** are the color coordinates on green-red and in blue-yellow axes, respectively. The spectrophotometer was calibrated prior to the measurements. The assessments were carried out using a D65 light source (6500 K), observer angle of 10º, and specular component excluded (SPEX). A drop of a coupling agent with a refractive index of 1.47 was used (glycerol $C_3H_8O_3$) to avoid the light dispersion between the sample and the background. Each sample was measured three times over each background and the average of these three measurements was used for color and translucency calculations. These measurements were taken at baseline and after 15 and 30 days of staining in red wine.

The values obtained over the gray background were used for color difference calculations with the CIEDE2000 formula (equation 1). The color alteration was calculated using the CIE*L*a*b** measurements at 15 and 30 days compared to the baseline CIE*L*a*b** values (mutual comparison). The perceptibility ($\Delta E_{00} > 0.8$) and unacceptability ($\Delta E_{00} > 1.8$) thresholds were considered for clinical inference[17].

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)\right]^{\frac{1}{2}} \qquad (1)$$

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are the differences in lightness, chroma, and hue, respectively, for a pair of measurements (baseline and 15 or 30 days of staining). The rotation function R_T accounts for the interaction between chroma and hue differences in the blue region. Weighting functions S_L, S_H, and S_C adjust the total color difference for variation in the location of the color difference pair in L', a', b' coordinates. The parametric factors K_L, K_C, and K_H are correction terms for deviation from reference experimental conditions. In this study, these parametric factors of the CIEDE2000 formula were set as 1.

The translucency parameter (TP_{00}) was also calculated with the CIEDE2000 formula (equation 1). However, the pair of measurements used were the CIE*L*a*b** parameters obtained from each sample over the white and black backgrounds, separately for baseline, and after 15 and 30 days of staining.

Statistical analysis

The statistical analysis was carried out using the SigmaPlot 12.0 (Systat Software Inc, San Jose, USA) software program. Data were subjected to normality (Shapiro-Wilk test) and homoscedasticity (Levene test) tests. Next, average roughness data were analyzed with the Kruskal-Wallis test. Color difference data were analyzed with two-way repeated-measures ANOVA (material*staining time) and Tukey's test as *post-hoc*. Translucency stability was analyzed separately for each material using the one-way repeated measures ANOVA test. The CAD/CAM blocks chosen for this study are available in different color scales, so that translucency comparisons among materials would be biased. The significance level was set at 5%.

Results

Table 2 shows the roughness mean values for each material after the polishing procedures. No significant difference was observed in the Ra parameter among the experimental groups (P > 0.05). The statistical analysis regarding color stability (described in Table 3) showed a significant effect from material (P = 0.002) and staining time (P < 0.001) on the studied outcome, as well as a significant interaction between these factors (P = 0.004). All three materials significantly increased their color alteration from 15 to 30 days of staining. PICN reached an intermediate color alteration between FEL and RC after 15 days. However, PICN revealed a color alteration as high as the resin composite after 30 days of staining, and the feldspathic ceramic was the most stable material. The restorative materials reached the color unacceptability threshold (ΔE_{00} > 1.8) after 15 days of staining. On the other hand, all three materials had their translucencies stable over the 30-day staining since no statistically significant differences were observed (Table 4).

Table 2. Means (standard deviations) of average roughness (Ra) of each experimental group after polishing procedures.

Materials	Ra (µm)
PICN	0.36 (0.08)^{a}
FEL	0.36 (0.22)^{a}
RC	0.27 (0.18)^{a}

Different lowercase letter within a column indicates statistical differences among groups (Kruskal-Wallis test, P < 0.05).

Table 3. Means (standard deviations) of color difference (ΔE_{00}) of each material after 15 and 30 days of staining in red wine.

Materials	ΔE_{00} 15 days	ΔE_{00} 30 days
PICN	3.74 (0.35)^{B,ab}	4.95 (0.80)^{A,a}
FEL	3.22 (1.04)^{B,b}	3.82 (1.24)^{A,b}
RC	4.22 (0.88)^{B,a}	5.49 (0.73)^{A,a}

Different uppercase letter within a row indicates significant statistical differences between immersion times of the same material. Different lowercase letter within a column indicates statistical differences among materials in the same immersion time measurement (Two-way RM ANOVA, Tukey's test, P < 0.05)

Table 4. Means (standard deviations) of translucency parameter (TP_{00}) of each material at baseline and after 15 and 30 days of staining in red wine.

Materials	TP_{00} baseline	TP_{00} 15 days	TP_{00} 30 days
PICN	13.02 (1.25)^{A}	13.52 (1.34)^{A}	12.77 (1.33)^{A}
FEL	21.23 (3.13)^{A}	21.11 (1.40)^{A}	20.39 (1.49)^{A}
RC	24.44 (3.35)^{A}	25.32 (1.28)^{A}	23.34 (1.16)^{A}

Distinct uppercase letter within a row indicates significant statistical differences among the immersion time measurements of the same material (One-way RM ANOVA, Tukey's test, P < 0.05).

Discussion

PICN exhibited the same color alteration as a machinable resin composite, which was less stable than a glass-ceramic after the total exposure time to red wine. However, its translucency was maintained throughout the 30 days of staining. This made the first and second tested hypotheses to be rejected and accepted, respectively.

All the materials reached the clinical unacceptability threshold at the first checkpoint (15 days). This observation was predictable since red wine has been described as the most pigmented beverage in *in vitro* studies[9,15]. The color stability of each material depends on the staining exposure time. PICN reached ΔE_{00} values similar to both composite and ceramic after the first 15 days of exposure to red wine. In contrast, its color alteration was statistically similar to the composite and greater than the glass-ceramic after 30 days. PICN has UDMA and TEGDMA monomers in their composition. Great water sorption has been reported in composites containing high TEGDMA content compared to other methacrylate monomers[23]. This is explained by the hydrophilicity of TEGDMA. In this sense, hydrophilic monomers facilitate pigment infiltrations leading to easier discoloration.

On the other hand, feldspathic ceramics consist of a vitreous matrix filled with silicon oxide and leucite crystals. Since glasses do not suffer water sorption as polymers, glass-ceramics are more resistant to discoloration than resin composites. To date, the manufacturer of Brava block does not disclose the main methacrylate monomers in the materials' composition. However, it is well known that resin composites are more color unstable than dental ceramics[8,15,24]. PICN has only 14 w% of UDMA and TEGDMA in its composition. Still, this amount of composite was sufficient to decrease its color stability when compared to a feldspathic ceramic. A previous study proposed a new classification for ceramic and ceramic-like materials[25]. They classified polymer-matrices containing predominantly inorganic refractory compounds as resin-matrix ceramics. In this sense, Vita Enamic and Brava block would be included in the same category, which also corroborates the similarity observed in our results.

In contrast to our results, previous studies have found the highest discolorations in resin composites, followed by PICN, and glass ceramics, which reach the lowest values after staining in red wine[9,26]. Nonetheless, these studies used the CIELAB formula for color difference calculations and days straight of immersion in the beverages. One should note that the CIEDE2000 formula is a more sophisticated tool which better represents the color differences perceived by the human eye than CIELAB[27,28]. Therefore, despite conflicting with previously published results, using CIEDE2000 for color and translucency calculations might bring more accuracy to the results of the present study.

According to the values obtained, the initial translucency of PICN would be lower than FEL and RC (Table 4). However, the CAD/CAM blocks used in this study are available in different color scales so that comparisons among the materials' translucency would be biased. Therefore, we evaluated the translucency stability of each material throughout the 30-day staining separately to avoid unfair comparisons. Our results showed that all the materials maintained their translucency values over the staining process. Previous studies have observed changes in translucency of PICN after being subjected to red wine[13,14]. Nevertheless, these studies were obtained from days straight of immersion in red wine, which might have overestimated the results. Authors that implemented staining protocols similar to the one used in the present study found no differences in the translucency of glass-ceramics or resin composites[8].

Previous studies have observed that surface finishing methods can increase roughness and consequently decrease the translucency[29], or lead to color alteration of restorative materials[8,30]. Different finishing approaches were performed in our study, since the FEL samples received a glaze layer and the RC and PICN samples were polished with Sof-Lex discs. This polishing sequence was chosen since diamond discs are frequently used in daily dental practice. Furthermore, the diamond disc sequence is suggested by the manufacturers for repair, pre-polishing, and/or polishing of PICN and RC[31,32]. Even at the risk of influencing the results due to the different surfaces, it was decided to reproduce finishing procedures closer to the clinical conditions. On the other hand, the initial roughness was proven to be similar among the experimental groups (Table 2). This evidences standardization of the samples regarding the surfaces subjected to the staining process.

The described results are somehow clinically applicable to patients who have a pigment-rich diet. We employed a 30-min immersion in red wine twice a day with 12 h of dwell time. The staining protocol is plausible since the aforementioned patients might keep their restorations in contact with pigments for this amount of time a day. Brushing is an important clinical factor and it was proven to reduce staining in resin composites[33] and to cause color alteration in glass-ceramics[34]. Nonetheless, brushing was not included in our study design. Even so, our findings indicate that polished PICN tends to behave as a composite regarding color stability when in contact with highly pigment beverages. Moreover, PICN has shown mechanical properties superior to composites[35,36], which must also be considered when choosing the best restorative material for each clinical scenario.

Conclusion

PICN was not as color stable as the feldspathic ceramic at the end of the study. Its color alteration was comparable to the resin composite when subjected to contact with red wine. All tested CAD/CAM materials reached the unacceptable threshold of discoloration already at 15 days of staining. However, the translucency of all restorative materials was stable throughout the 30-day staining protocol.

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Conflicts of interest: none

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