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Effect of thickness on color and translucency of a multi-color polymer-infiltrated ceramic-network material

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Abstract

Objectives: To evaluate the effect of thickness on color and translucency of a multi-color polymer-infiltrated ceramic-network (PICN) material.

Methods: Specimens of 0.5, 1.0, 1.5 mm thicknesses were obtained by sectioning VITA ENAMIC® multiColor (E-MC) High Translucent CAD-CAM blocks (1M1-HT, 1M2-HT, 2M2-HT, 3M2-HT, and 4M2-HT). Spectral reflectance and color coordinates were measured on white and black backgrounds using a spectroradiometer, CIE D65 illuminant and CIE 45°/0° geometry. CIEDE2000 color and translucency differences (ΔE_{00} and ΔTP_{00}) between thicknesses and adjacent layers were evaluated using their respective 50:50% perceptibility and acceptability thresholds (PT_{00} and AT_{00}).

Results: In general, ΔE_{00} between thicknesses for all shades and layers were above AT_{00} in general. Chroma decreased from cervical to incisal layers with statistically significant differences ($p < 0.05$), and ΔE_{00} between sequential layers were above PT_{00}, for all shades and thicknesses. TP_{00} decreased from 0.5 to 1.5 mm and increased from cervical to incisal layers for all shades with statically significant translucency differences ($p < 0.05$). In general, for all thicknesses, $TPT_{00} < \Delta TP_{00} < TAT_{00}$ for sequential layers.

Conclusions: The gradient in color and translucency of E-MC PICN material was influenced by the thickness of the CAD-CAM block. In addition, color and TP transition values between the layers depends on the thickness and shade.

Clinical significance: The effect of thickness must be taken into account by dental technicians and dentists when CAD-CAM multicolor PICN materials are used.

KEYWORDS
color, PICN material, thickness, translucency parameter, visual thresholds

1 | INTRODUCTION

Multi-color polymer infiltrated ceramic network (PICN) materials are CAD-CAM resin-matrix ceramics with a predominately inorganic phase that combine positive properties of both ceramics and composites.[1] PICN materials offer similar flexural resiliency and improved fractured resistance compared to composite resin, and lower hardness than ceramics.[2–4] This material is indicated to the manufacture of minimally invasive unitary restorations in both the anterior and posterior sector (veneers, inlays, crowns and implant crowns).[5]

Natural teeth color is given by the combination of optical properties from enamel and dentine. The thickness, structure and composition of these tissues change through different areas of the tooth, which explains an overall gradation in color from cervical, which is the most chromatic, to incisal region.[6,7] This concept was applied to PICN materials resulting in the multilayer blocks such as Vita Enamic Multi-Color (E-MC).

A recent study[8] evaluated optical properties and color of samples of the shades from E-MC, showing that chroma increased from incisal to cervical with, in general, perceptible CIEDE2000 color differences (ΔE_{00}) between sequential layers for all shades. In addition, it was found that CIEDE2000 translucency parameter (TP_{00}) increased from cervical to incisal with acceptable translucency parameter differences ($TPT_{00} < \Delta TP_{00} < TAT_{00}$) between sequential layers. Thus, the gradient in color and translucency of CAD-CAM multi-color PICN material appears to be proven.

In clinical setting, the final appearance of an indirect esthetic restoration is determined by other properties in addition to the color or translucency of the material, such as its thickness.[9] A study[10] demonstrated that the a^* and b^* coordinate values, and therefore C^* value, of CAD-CAM ceramic decreases with increasing ceramic thickness, while the differences in lightness parameter (L^*) was ceramic-shade dependent. Another study found a decrease in translucency and a reddish-blue appearance of monolithic zirconia ceramic with increasing material thickness.[11]

On the other hand, a recent research[12] showed that the translucency parameter (TP) of the monolithic CAD-CAM restorative materials was influenced by the type and thickness of the material. Other study[13] concluded that TP and the relative translucency parameter (RTP) values of ceramic studied materials decreased with increasing thickness. Moreover, TP was used for the measurement of translucency of tooth enamel and dentin.[14]

In addition, the effect of thickness on color appearance and TP of four brands of A3-shade multilayer CAD/CAM composite resin (Katana Avencia, CERASMART Multi, KZR-CAD HR Block 4 E-va, and Block HC Hard AN) were recently studied.[15] The authors stated that the color appearance of CAD/CAM blocks was significantly influenced by both the thickness and layer (incisal, cervical or middle). L^*, a^*, b^* coordinates values decreased with thickness and TP decreased with increasing block thickness, and that thicker specimens were lighter, more red, and yellow than thinner specimens, as showed by previous studies.[16,17] Also, the authors[15] found a negative exponential relationship between TP and thickness for all layers and brands. However, only a shade was studied and color and translucency differences were not analyzed and interpreted in terms of translucency thresholds values published.[18,19]

In dentistry, most studies[15,20–23] evaluate the effect of thickness on color or TP by calculating color differences using either CIELAB or CIEDE2000 color difference formulas. However, the success of an esthetic restoration depends on its final appearance and on an acceptable color matching with the adjacent structures, rather than numerical data alone. Therefore, the interpretation of color and translucency difference values should be associated with the acceptability (AT) and perceptibility thresholds (PT), in order to correlate numerical data with clinical observations and perceptions, and to assess and report the clinical significance of the results.[18,19,24,25] Recently, in this context, novel algorithms from the artificial intelligence field have been used for obtaining color and TP thresholds in dentistry.[26] To the best of our knowledge, no information is available on the effect of thickness on color and translucency of CAD-CAM multi-color PICN material based on visual thresholds.

The aim of this study was to evaluate the influence of thickness on color and translucency of a multi-color polymer-infiltrated ceramic-network (PICN) material. The hypotheses tested were that: (i) color and translucency values of PICN materials are influenced by thickness, and (ii) PICN materials present a perceptible difference in color and TP between the sequential layers regardless of the thickness.

2 | MATERIALS AND METHODS

2.1 | Specimen preparation

The material used in this study was VITA ENAMIC multicolor (E-MC) High Translucent (HT) (Vita Zahnfabrik, Bad Säckingen, Germany) in all available shades (Table 1). Three slices (12.0×14.0 mm) of each shade were obtained for three thickness: 0.5, 1.0, and 1.5 mm ($n = 45$), were obtained from perpendicularly cutting each CAD-CAM block with a diamond disk using an Accutom-50 (Struers, Ballerup, Denmark). According to the manufacturer information, the height of each layer was 2.3 mm. Specimens were polished with silicon carbide paper discs (500, 800, 1000, 2000, and 2500 grits) and sonically cleaned in distilled water for 5 min. During the polishing sequence and at the end, each specimen was measured with a digital caliper (Mitutoyo, Europe GmbH, Germany) to control the achievement of the required final thickness (±0.01 mm).

2.2 | Spectral reflectance and color measurements

Spectral reflectance of E-MC specimens was measured against white ($L^* = 94.2$, $a^* = 1.3$ and $b^* = 1.7$) and black ($L^* = 3.1$, $a^* = 0.7$ and $b^* = 2.4$) 50×50 mm ceramic tile backgrounds (Ceram, Staffordshire, United Kingdom), using a non-contact measuring experimental device. The spectroradiometer (PR-670, PhotoResearch, Chatsworth, CA, USA) was placed 40 cm from the specimens with a 0.125° measuring area and the illuminating/measuring geometry used corresponding to the CIE 45°/0°. A manual XYZ axis translation stage (MAXYZR-60L-P-H, Optics Focus Instruments, Beijing, China) was used to ensure precise movements between layers. A saturated solution of sucrose was placed as optical contact between each specimen and background.[6]

Spectral reflectance values were converted into CIE $L^*a^*b^*$ color coordinates using the CIE 2° Standard Observer and the CIE D65 Standard Illuminant,[27] and finally chroma (C^*) and hue (h^o) coordinates were calculated. Three short-term repeated reflectance measurements without replacement were performed, and the results were averaged.

Computations for CIEDE2000 (ΔE_{00})[27,28] color differences were used according the following equation:

TABLE 1 Information on the polymer-infiltrated ceramic-network (PICN) material evaluated in the study

Material	Manufacturer	Filler content (wt%)	Composition	Shades	Layers
Vita Enamic multiColor High Translucent (E-MC)	Vita Zahnfabrik, Bad Sackingen, Germany	86.0	Feldspathic ceramic (SiO_2 (58 wt%), Al_2O_3 (20 wt%), Na_2O (9 wt%), K_2O (4 wt%), B_2O_3 (0,5 wt%), ZrO_2 (<1%) y CaO (<1%))	1M1-HT 1M2-HT 2M2-HT 3M2-HT 4M2-HT	E-MC 1 (cervical) E-MC 2 E-MC 3 E-MC 4 E-MC 5 E-MC 6 (incisal)
		14,0	UDMA, TEGDMA		

Note: All data were provided by the manufacturer.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)},$$

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are the differences in lightness, chroma, and hue for a pair of layers. R_T is a function that accounts for the interaction between chroma and hue differences in the blue region. The weighting functions, S_L, S_C, and S_H adjust the total color difference for variation in the location of the color difference pair in L', a', and b' coordinates and the parametric factors k_L, k_C, and k_H are correction terms for experimental conditions. In the present study, $k_L = k_C = k_H = 1$ was considered.

Color differences between two adjacent layers from same shade and thickness, and between layers of different thickness from same shade, were finally evaluated using the 50%:50% perceptibility and acceptability ($PT_{00} = 0.81$ and $AT_{00} = 1.77$ ΔE_{00} units) color thresholds.[24,29]

2.3 | Translucency parameter

Translucency parameter (TP_{00})[30] values were determined by calculating CIEDE2000 color difference formula (ΔTP_{00}) between the color readings over the black and white backgrounds, according to the following equation[19]:

$$TP_{00} = \sqrt{\left(\frac{L'_B - L'_W}{k_L S_L}\right)^2 + \left(\frac{C'_B - C'_W}{k_C S_C}\right)^2 + \left(\frac{H'_B - H'_W}{k_H S_H}\right)^2 + R_T \left(\frac{C'_B - C'_W}{k_C S_C}\right)\left(\frac{H'_B - H'_W}{k_H S_H}\right)},$$

where the subscripts "B" and "W" refer to color coordinates of each layer over the black and the white backgrounds, respectively.

Finally, translucency differences (ΔTP_{00}) between two adjacent layers from the same shade and thickness, and between layers of different thickness from the same shade were evaluated in accordance with the 50%:50% translucency perceptibility and acceptability ($TPT_{00} = 0.62$ and $TAT_{00} = 2.62$) thresholds.[19]

2.4 | Statistical analysis

Levene test was used, and the normality and variance homogeneity assumptions for all color coordinates (L^*, C^*, h^o) and translucency parameter were satisfied. To analyze the differences between sequential layers from the same shade and thickness, and between layers of different thickness from the same shade for each color coordinate and TP, one-way ANOVA test and Fisher's PLSD intervals comparisons were used ($p < 0.05$). Statistical analysis was performed using a standard statistical software package (SPSS Statistics 20.0.0, IBM Armonk, New York USA).

3 | RESULTS

Mean and standard deviation values of CIELAB coordinates L^*, C^*, and h^o (degree) for all layers from all E-MC shades and all thickness are presented in Table 2. For all shades and thicknesses, mean L^* and C^* values decreased from cervical to incisal layers, but only statistically significant differences were found for chroma ($p < 0.05$). Mean hue (h^o) values showed no significant differences between layer for all shades and all thickness studied ($p \geq 0.05$).

Table 3 shows color differences (ΔE_{00}) between two adjacent layers within the same shade and the same thickness. In general, ΔE_{00} between sequential layers for all shade and all thickness were above PT_{00} value. Only ΔE_{00} values were below PT between layers E-MC1 and E-MC2 for 4M2-HT shade and for the three thickness (0.46, 0.81, and 0.74 ΔE_{00} units for 0.5, 1.0 and 1.5 mm, respectively), and 1M1-HT shade for 1.0 mm (0.76 ΔE_{00} units) and 1.5 mm (0.81 ΔE_{00} units). Figure 1 presents color differences between layers of different thickness from the same shade. Overall, ΔE_{00} for all shades and layers (from cervical to incisal) were above AT_{00}, except between 1.0 and 1.5 mm thicknesses for E-MC2 to E-MC5 layers of the 3M2-HT shade, E-MC2 and E-MC 3 layers for the 4M2-HT shade, E-MC 1 of the 2M2-HT shade and E-MC2 of the 1M1-HT shade. The color changes are mainly due to the increase of the value of lightness and chroma with increasing thickness (Table 1).

Figure 2 shows mean values of TP_{00} for all layers from different shades of E-MC and for all thicknesses. Translucency decreased from 0.5 mm to 1.5 mm and increased from cervical to incisal layers (E-MC 1 to E-MC 6) for all shades with statically significant translucency differences ($p < 0.05$). This behavior was found for all thickness with a range of values of 14.03–25.26 TP_{00} units for 0.5 mm thick, 9.21–18.02 TP_{00} units for 1.0 mm thick, and 6.17–15.73 TP_{00} units for 1.5 mm thick. 4M2-HT shade showed the lowest TP_{00} values for all layers and thicknesses.

TABLE 2 Mean values and SD of chromatic coordinates L^*, C^* y $h°$ for all layers, shades, and thicknesses

		L^*			C^*			$h°$		
		0.5 mm	1.0 mm	1.5 mm	0.5 mm	1.0 mm	1.5 mm	0.5 mm	1.0 mm	1.5 mm
1M1-HT	E-MC 1	72.61 (0.07)	76.43 (0.04)	77.51 (0.02)	4.34 (0.04)	7.60 (0.07)	9.90 (0.03)	−1.41 (0.03)	−1.51 (0.03)	−1.51 (0.07)
	E-MC 2	71.23 (0.05)	75.40 (0.05)	76.60 (0.02)	4.26 (0.06)	7.54 (0.06)	9.43 (0.04)	−1.40 (0.01)	−1.49 (0.03)	−1.54 (0.02)
	E-MC 3	69.52 (0.05)	73.71 (0.03)	75.18 (0.03)	3.00 (0.01)	6.38 (0.08)	8.29 (0.05)	−1.35 (0.06)	−1.44 (0.02)	−1.52 (0.07)
	E-MC 4	67.14 (0.01)	71.88 (0.09)	73.65 (0.04)	1.46 (0.09)	4.75 (0.04)	6.44 (0.01)	−1.24 (0.07)	−1.45 (0.05)	−1.53 (0.01)
	E-MC 5	65.66 (0.07)	69.99 (0.04)	71.96 (0.01)	0.60 (0.08)	3.26 (0.08)	5.01 (0.03)	−0.68 (0.04)	−1.42 (0.01)	1.54 (0.06)
	E-MC 6	64.10 (0.01)	68.54 (0.07)	69.40 (0.09)	0.77 (0.08)	1.98 (0.02)	4.06 (0.08)	0.65 (0.01)	−1.55 (0.07)	0.99 (0.05)
1M2-HT	E-MC 1	67.95 (0.06)	72.69 (0.08)	73.80 (0.02)	6.71 (0.02)	10.96 (0.06)	13.44 (0.09)	−1.43 (0.07)	−1.51 (0.01)	−1.52 (0.06)
	E-MC 2	66.14 (0.06)	71.51 (0.06)	72.72 (0.08)	5.45 (0.06)	10.52 (0.02)	13.72 (0.04)	−1.39 (0.06)	−1.49 (0.01)	−1.52 (0.07)
	E-MC 3	64.82 (0.08)	70.70 (0.03)	71.67 (0.06)	4.32 (0.02)	9.26 (0.02)	12.23 (0.01)	−1.29 (0.01)	−1.45 (0.05)	−1.51 (0.04)
	E-MC 4	63.01 (0.08)	68.47 (0.09)	69.86 (0.05)	2.70 (0.04)	6.64 (0.04)	9.35 (0.03)	−1.23 (0.01)	−1.42 (0.02)	−1.54 (0.04)
	E-MC 5	62.81 (0.06)	67.35 (0.04)	68.63 (0.02)	1.37 (0.06)	4.67 (0.06)	6.77 (0.04)	−0.94 (0.03)	−1.38 (0.03)	−1.53 (0.09)
	E-MC 6	63.25 (0.02)	67.38 (0.07)	68.16 (0.08)	0.80 (0.03)	3.65 (0.01)	5.36 (0.06)	−0.30 (0.05)	−1.36 (0.04)	1.43 (0.01)
2M2-HT	E-MC 1	68.09 (0.03)	71.09 (0.07)	72.06 (0.06)	8.71 (0.03)	13.97 (0.09)	16.30 (0.03)	−1.55 (0.06)	1.53 (0.06)	1.49 (0.08)
	E-MC 2	65.87 (0.08)	69.43 (0.04)	70.90 (0.04)	7.19 (0.06)	12.84 (0.04)	15.81 (0.06)	−1.55 (0.04)	1.54 (0.04)	1.50 (0.09)
	E-MC 3	64.79 (0.01)	69.01 (0.07)	69.88 (0.05)	5.97 (0.03)	11.09 (0.02)	13.44 (0.07)	−1.49 (0.08)	1.56 (0.05)	1.51 (0.08)
	E-MC 4	62.39 (0.05)	66.98 (0.05)	68.94 (0.04)	3.71 (0.08)	8.02 (0.07)	11.31 (0.02)	−1.49 (0.07)	1.57 (0.01)	1.51 (0.01)
	E-MC 5	61.48 (0.02)	65.29 (0.07)	67.16 (0.01)	1.62 (0.09)	5.72 (0.02)	8.88 (0.02)	−1.40 (0.09)	−1.53 (0.07)	1.51 (0.03)
	E-MC 6	59.98 (0.09)	64.07 (0.03)	64.58 (0.03)	0.67 (0.07)	4.31 (0.01)	6.40 (0.03)	1.46 (0.05)	1.52 (0.06)	1.11 (0.03)
3M2-HT	E-MC 1	62.90 (0.02)	65.37 (0.04)	66.13 (0.01)	11.32 (0.02)	16.14 (0.07)	19.09 (0.05)	−1.54 (0.08)	1.55 (0.04)	1.50 (0.02)
	E-MC 2	62.08 (0.06)	64.94 (0.07)	64.53 (0.07)	10.61 (0.04)	17.89 (0.09)	18.19 (0.09)	−1.57 (0.05)	1.54 (0.07)	1.51 (0.01)
	E-MC 3	61.05 (0.05)	64.10 (0.08)	63.65 (0.04)	9.34 (0.01)	15.91 (0.02)	16.72 (0.05)	−1.51 (0.09)	1.55 (0.05)	1.52 (0.07)
	E-MC 4	59.27 (0.09)	63.38 (0.04)	63.52 (0.03)	6.14 (0.06)	13.42 (0.05)	13.72 (0.05)	−1.46 (0.06)	1.57 (0.01)	1.52 (0.05)
	E-MC 5	57.07 (0.06)	61.26 (0.06)	62.14 (0.04)	4.20 (0.05)	9.63 (0.08)	10.75 (0.03)	−1.43 (0.09)	−1.56 (0.04)	1.53 (0.05)
	E-MC 6	55.91 (0.08)	60.77 (0.03)	61.13 (0.01)	3.01 (0.07)	6.35 (0.02)	8.62 (0.05)	−1.33 (0.03)	1.46 (0.02)	1.23 (0.09)
4M2-HT	E-MC 1	61.84 (0.01)	63.73 (0.09)	63.28 (0.09)	12.66 (0.03)	17.23 (0.08)	19.44 (0.01)	1.51 (0.03)	1.44 (0.04)	1.38 (0.07)
	E-MC 2	61.45 (0.05)	62.96 (0.03)	62.42 (0.05)	12.20 (0.06)	17.97 (0.05)	19.64 (0.09)	1.51 (0.02)	1.43 (0.02)	1.39 (0.07)
	E-MC 3	60.77 (0.01)	62.46 (0.06)	62.61 (0.05)	9.19 (0.01)	15.58 (0.09)	18.06 (0.07)	1.52 (0.03)	1.46 (0.02)	1.41 (0.09)
	E-MC 4	59.88 (0.08)	61.70 (0.04)	62.65 (0.03)	7.40 (0.04)	11.94 (0.04)	15.54 (0.05)	−1.56 (0.04)	1.51 (0.05)	1.44 (0.08)
	E-MC 5	60.19 (0.08)	60.68 (0.07)	62.44 (0.09)	5.23 (0.03)	9.97 (0.06)	14.15 (0.06)	−1.53 (0.05)	1.51 (0.01)	1.45 (0.03)
	E-MC 6	60.21 (0.07)	58.53 (0.05)	62.02 (0.04)	3.59 (0.02)	8.02 (0.02)	11.01 (0.03)	−1.45 (0.05)	1.22 (0.01)	1.33 (0.07)

TABLE 3 Color differences (ΔE_{00}) between sequential layers for the same shade and thickness

ΔE_{00}						
Thickness	Shade	E-MC1 - E-MC2	E-MC2 - E-MC3	E-MC3 - E-MC4	E-MC4 - E-MC5	E-MC5 - E-MC6
0.5 mm	1M1	1.04	1.72	2.36	1.54	1.55
	1M2	1.77	1.52	2.09	1.34	0.92
	2M2	2.11	1.40	2.74	2.03	1.65
	3M2	0.92	1.48	2.86	2.54	1.52
	4M2	0.46[a]	2.12	1.72	1.72	1.43
1.0 mm	1M1	0.76[a]	1.59	1.90	1.93	1.71
	1M2	0.97	1.14	2.61	1.82	0.87
	2M2	1.46	1.24	2.69	2.25	1.65
	3M2	1.09	1.34	1.65	3.09	2.73
	4M2	0.81[a]	1.59	2.54	1.59	4.07
1.5 mm	1M1	0.81[a]	1.32	1.80	1.78	3.90
	1M2	0.83	1.23	2.42	2.13	1.88
	2M2	0.93	1.66	1.56	2.19	4.74
	3M2	1.41	1.14	1.78	2.25	4.07
	4M2	0.74[a]	1.07	1.58	0.87	2.65

[a]Values below the perceptibility threshold (PT_{00}).

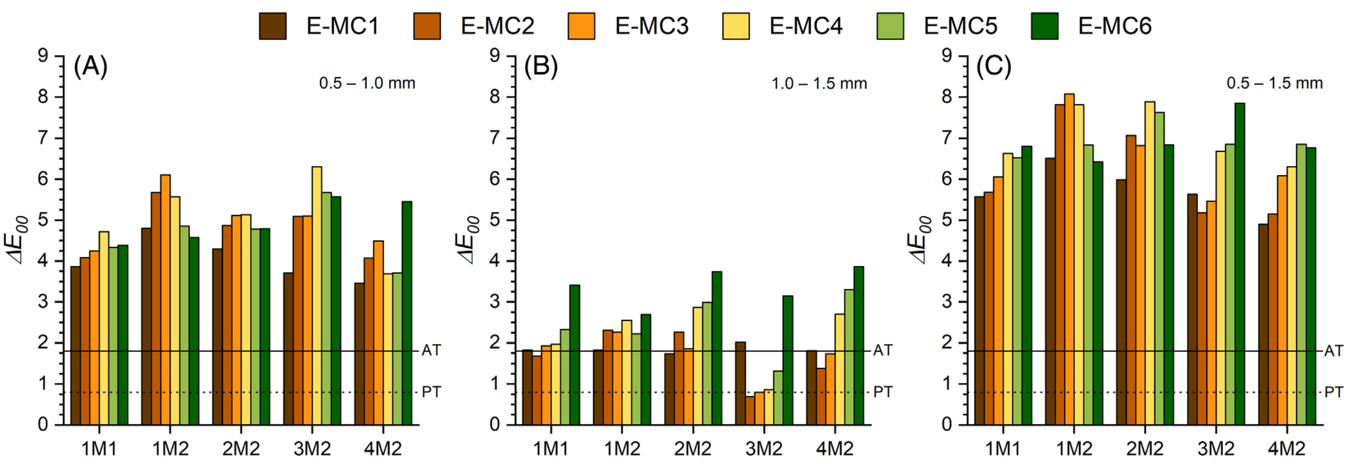

FIGURE 1 Color differences (ΔE_{00}) between layers of different thickness from the same shade. (A) 0.5–1.0 mm; (B) 1.0–1.5 mm; (C) 0.5–1.5 mm

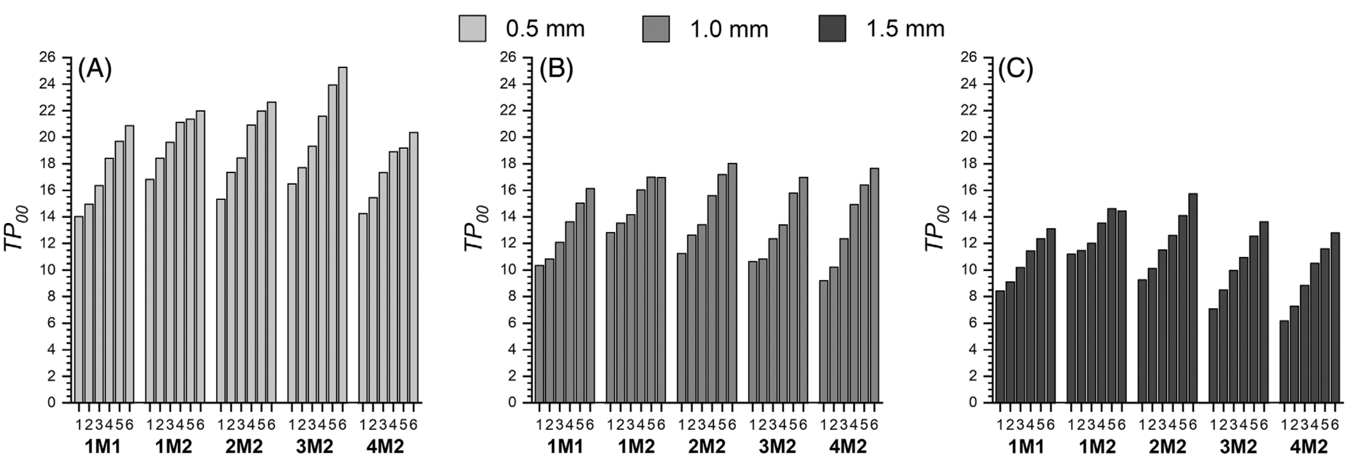

FIGURE 2 Mean values of translucency parameters TP_{00} for all layers, shades and thicknesses. (A). 0.5 mm; (B) 1.0 mm; (C) 1.5 mm

TABLE 4 Translucency differences (ΔTP_{00}) between sequential layers for the same shade and thickness

ΔTP_{00}						
Thickness	**Shade**	**E-MC1–E-MC2**	**E-MC2–E-MC3**	**E-MC3–E-MC4**	**E-MC4–E-MC5**	**E-MC5–E-MC6**
0.5 mm	1M1	0.94	1.39	2.06	1.29	1.17
	1M2	1.60	1.19	1.51	0.24[a]	0.62[a]
	2M2	2.02	1.10	2.46	1.05	0.67
	3M2	1.21	1.63	2.25	2.38	1.32
	4M2	1.21	1.77	1.60	0.26[a]	1.19
1.0 mm	1M1	0.49[a]	1.25	1.56	1.39	1.10
	1M2	0.73	0.62[a]	1.89	0.96	0.05[a]
	2M2	1.39	0.77	2.18	1.61	0.82
	3M2	0.20[a]	1.53	1.03	2.38	1.19
	4M2	1.02	2.13	2.55	1.50	1.24
1.5 mm	1M1	0.68	1.10	1.26	0.90	0.74
	1M2	0.28[a]	0.53[a]	1.53	1.07	0.17[a]
	2M2	0.87	1.39	1.09	1.50	1.64
	3M2	1.44	1.47	0.98	1.59	1.07
	4M2	1.12	1.56	1.66	1.08	1.21

[a]Values below the perceptibility threshold (TPT_{00}).

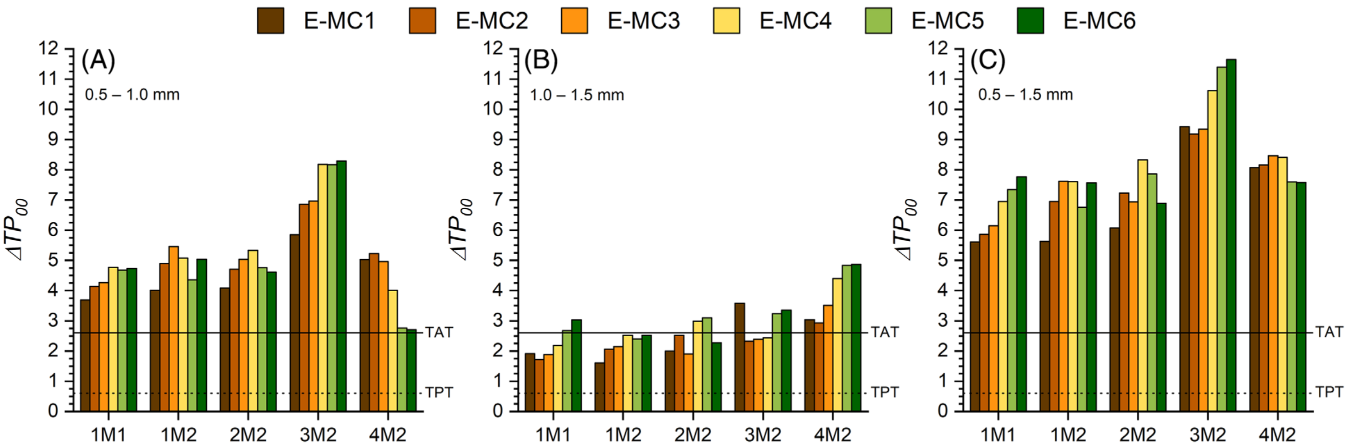

FIGURE 3 Tranlucency differences (ΔTP_{00}) between layers of different thickness from the same shade. (A) 0.5–1.0 mm; (B) 1.0–1.5 mm; (C) 0.5–1.5 mm

Table 4 shows ΔTP_{00} between sequential layers within the same shade and thickness. In general, ΔTP_{00} between sequential layers were above TPT_{00} value, and only ΔTP_{00} values were below TPT_{00} between layers E-MC1-E-MC2 for 1M1-HT and 3M2-HT for 1.0 mm and 1M2-HT for 1.5 mm. Also, between E-MC2-E-MC3 for 1M2-HT for 1.0 and 1.5 mm, between E-MC4-E-MC5 for 1M2-HT and 4M2-HT for 0.5 mm, and between E-MC5-E-MC6 for 1M2-HT by all thickness. All ΔTP_{00} between sequential layers were below TAT_{00} (ΔTP_{00} < 2.62 units) for all thicknesses.

Figure 3 shows translucency parameter differences between layers of different thickness from the same shade. ΔTP_{00} are larger than translucency acceptability thresholds except between 1.0 and 1.5 mm thickness for all E-MC layers of the 1M2-HT shade, E-MC1–E-MC4 of 1M1-HT, E-MC1–E-MC3 and E-MC6 for 2M2-HT shade and E-MC2–E-MC4 for 3M2-HT which are $TPT_{00} < \Delta TP_{00} < TAT_{00}$. Thus, the results showed that, in general, the incisal layer (E-MC6) and the most chromatic shades, 3M2-HT and 4M2-HT (Table 1), presented the greatest change in translucency due to thickness.

4 | DISCUSSION

The influence of thickness of composite resin and conventional ceramic on their esthetic appearance has been studied for years.[15,20–23]

The relationship between material thickness and its translucency and colorimetric properties is not linear and depends, among other factors, on the type of material, composition, filler particles and filler percentage.[22,23] Therefore, achieving an esthetic dental restoration simulating the complex natural appearance of the tooth is directly influenced, not only by the type of material and shade selection, but also by its thickness.

With the intention to simulate the color gradient of natural tooth, a multi-color polymer-infiltrated ceramic-network (PICN) material, VITA ENAMIC multiColor (E-MC), has been introduced. A recent study[8] states that E-MC presents a chromatic perceptible transition integrated in six layers from cervical to incisal layer. However, no information is available on the effect of the thickness on color and translucency gradient of such material. In this context, this study evaluated the effect of thickness on the color and translucency of E-MC using the CIEDE2000 color difference formula for computing color and translucency parameter (ΔE_{00} and ΔTP_{00}) and their 50:50% perceptibility and acceptability (PT_{00}, AT_{00}, TPT_{00} and TAP_{00}) thresholds as application and interpretation on color and TP changes. Several investigations[18,24] demonstrated that ΔE_{00} color difference formula,[28] currently recommended by CIE,[27] incorporates specific corrections for no uniformity of CIELAB color space, providing a higher degree of fit than CIELAB color difference formula, for both color difference perceptibility and acceptability.[24]

The present study confirmed the first hypothesis since all layers from all shades of E-MC showed color and translucency differences above their respective perceptibility thresholds, and in the most of the cases above the acceptability thresholds (Figures 1 and 3). Lightness (L^*) and chroma (C^*) increase with increasing thickness, however, hue not show a clear behavior, especially between layers of the same shade. Nevertheless, the differences found for the hue are, in general, below hue acceptability thresholds published in the literature.[25] These results suggest that all layers (cervical to incisal) of all shades become brighter and more saturated (high chroma) but maintaining the hue, with increasing specimen thickness. This result differs in part with the results obtained by Ha *et al*.,[15] which indicated that all layers (cervical, middle and incisal) became darker and yellower (hue change) with decreasing specimen thickness.

Translucency parameter decreased with increasing specimen thickness for all shades and layers (E-MC1- E-MC6). This result is according with previous literature,[15,20–23] which reported a decrease in TP with increasing thickness. E-MC material showed ΔTP_{00} above acceptability translucency thresholds, except between specimens of 1.0 and 1.5 mm, most of which are $TPT_{00} < \Delta TP_{00} < TAT_{00}$ (Figure 3B), which suggest changes in the appearance of translucency. In clinical setting, this implies that even small changes in the thickness of PICN block can cause a significant change in TP.

Generally, this effect is lower in cervical layers (E-MC1 and E-MC2) suggesting that TP was influenced by both the thickness and layer as stated by Ha *et al*.,[15] Also, this effect is greater for high chroma shades (3M2 and 4M2). This result was expected since the color of the composite resins and/or ceramic materials[16,17] influenced their translucency value. The more chromatic shades were less translucent (Figure 2), with a negative correlation between the chroma and the TP parameter.

To the best of our knowledge, there is no data available on TP_{00} human dentin and human enamel. The translucency parameter calculated using CIELAB color difference (TP_{ab}), reported[14] TP_{ab} values of 18.7 and 16.4 units for 1.0 mm thick human enamel and dentin, respectively. Nevertheless, previous studies[8,19] showed lower TP_{ab} values using CIEDE2000 (TP_{00}) formula. Therefore, TP_{00} values found for 1.0 mm specimens, ranging from the 4M2-HT, E-MC 1 (9.21 TP_{00} units) to 2M2-HT, E-MC 6 (18.02 TP_{00} units), were close to human dentin and enamel for the incisal layers.[14] However, to obtain similar values for the cervical layers, thickness should be reduced to 0.5 mm, which ranged from 14.03 (1M1-HT, E-MC 1) to 25.26 (3M2-HT, E-MC 6) TP_{00} units.

Ha *et al*., showed how the TP_{ab} values decreased sequentially while increasing the thickness,[15] being consistent with previous literature[20–23] as well as with the results obtained in the present study, although the materials studied by Ha *et al*., were considerably more translucent than the E-MC (Figure 3).

Color and translucency properties dental materials must be evaluated considering the same characteristic of the natural teeth. Thus, the color and translucency gradient of natural tooth should be simulated to obtain an esthetic dental restoration. A study[7] showed perceptible color differences between the cervical-middle, middle-incisal and cervical-incisal regions from different teeth. In the present study, VITA ENAMIC® multiColor has experimentally demonstrated a favorable gradient of color and translucency for all thickness studied. ΔE_{00} between the layers of transition between dental thirds (E-MC2 and E-MC3 and E-MC4 and E-MC5) were higher than PT_{00}, and, therefore, visually perceptible for all E-MC shades. Also, perceptible color differences was found between E-MC3 and E-MC4 and E-MC5 and E-MC6 for all shades. For all thicknesses evaluated, mean L^* and C^* values decreased from cervical to incisal layers (E-MC1–E-MC6) with differences above PT_{00} values between cervical (E-MC1 and E-MC2) and incisal (E-MC5 and E-MC6) layers.[25] These results showed a perceptible gradient in lightness and chroma, while no perceptible variations in hue,[25] given that is not influenced by the layer and thickness of the block.

TP_{00} values from different shades of E-MC tend to increase from cervical (E-MC1) to incisal (E-MC6) (Figure 2) as described for natural teeth; this finding is consistent with previous research studies[8,15] on multi-layer materials. Translucency differences between adjacent layers (Table 3) were, in general, higher than TPT_{00}, and, in all cases, lower than translucency acceptability thresholds (TAT_{00}), showing a highest value of 2.55 TP_{00} units (Table 4), similar to the maximum of 2.75 TP_{ab} units reported by Ha *et al*.,[15] for the three-layer materials studied.

This behavior was found for all the thicknesses evaluated, and it is congruent with the translucent appearance of natural teeth. Thus, since in general, all layers (from cervical to incisal) from all shades of E-MC and for all thicknesses showed visually perceptible differences in color and translucency, the second hypothesis was accepted.

Regarding the color differences obtained between layers, Ha *et al*., found similar ranges for all the thicknesses studied that varied from 1.23 to 5.92 ΔE_{00} units,[15] which is also shown in our results (Table 3) although with a larger range, mainly due to the difference in layers between the materials studied, as well as the length of the color gradient included, providing a high versatility for its clinical application. However, the translucency differences between adjacent layers in E-MC differ depending on the thickness, as can be observed in Table 3. It is important to highlight that the color differences between sequential layers were, in most cases, higher than the respective PT thresholds, meaning that the observer will be able to differentiate the chromatic changes between layers in a restoration performed with this material.

Given the influence showed by thickness and layer on the color and translucency of multi-color materials, future experimental studies will focus on to the development of a three-dimensional color and translucency gradient CAD-CAM multilayer material (not just from cervical to incisal), similar to the natural appearance of the human tooth structure. Advances based on new applications of artificial intelligence in dentistry,[26] as well as the recent technology of 3D-printed restorative materials, could help on the development of these materials.

5 | CONCLUSIONS

Within the limitations of this study, the following conclusions were obtained:

- The gradient in color and translucency of CAD-CAM E-MC PICN material was influenced by the thickness. From cervical to cervical layers (E-MC1- E-MC6), lightness and chroma increase with increasing thickness while the translucency decreased.
- Color and translucency differences between adjacent layers of E-MC material were visually perceptible regardless of thickness of the CAD-CAM block. However, the color and translucency transition values between the layers depend of the thickness and shade. Such behavior must be taken into account by dental technicians and dentists when CAD-CAM multicolor PICN materials are used.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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