Colorimetric analysis of dental porcelains: effects of the background color

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Abstract

This study evaluated how the background (white or gray) affects the color parameter measurements and color difference calculations (ΔE_{ab} and ΔE_{00}) of dental ceramics. Disc-shaped feldspathic ceramic specimens were prepared with two shades (enamel and dentin) and stained in red wine (7-day immersion). A spectrophotometer was used to perform color measurements (CIEL*a*b* coordinates) over gray and white backgrounds after the specimen preparation and after staining. The color difference was calculated with CIEDE2000 (ΔE_{00}) and CIELAB (ΔE_{ab}) formulae. Initial L*a*b* coordinates, ΔE_{00}, and ΔE_{ab} data were analyzed with t-tests separately for each ceramic shade. White background led to higher values of L* and b* coordinates from the enamel shade, and of L*, a*, and b* coordinates from the dentin shade. However, ΔE_{00} and ΔE_{ab} results from white and gray backgrounds were similar in both ceramic shades. Therefore, background color did not affect the color difference results of the slightly stained feldspathic ceramic samples.

Keywords: dental ceramic, color, CIEL*a*b* system.

INTRODUCTION

Dental glasses and ceramics are restorative materials that meet the demand for esthetically appealing situations. Particularly, the porcelains used with the layering technique allow the most esthetical results by the combination of different shades and opacities in the same restoration. The porcelains are feldspathic ceramics usually applied over a stronger substructure material (e.g., metal alloys, zirconia) and can match the natural tooth appearance in terms of translucency, color, and texture [1]. Color is a fundamental aspect of dental esthetics. Thus, there is a constant need to understand the restorative materials' optical behavior in different surface treatments or staining challenging environments. Color determination of natural teeth or restorative materials is commonly performed from its reflected light with visual or instrumental approaches. Instrumental perception of optical properties has been preferred since it provides objective and quantifiable measures by a numerical description of the color parameters [2].

Spectrophotometers are one of the most accurate and used devices for color evaluation in Dentistry applications [3]. These instruments have an optical radiation source, a light dispersion mean, an optical measurement system, a detector, and a conversion method of the measured light into a signal that can be properly analyzed [4]. Such conversion is usually done to the CIEL*a*b* color space, which is a standard of the Commission Internationale de l'Éclairage (CIE), international authority for light, illumination, color, and color spaces. Hence, most spectrophotometers quantify color by coordinates in the three-dimensional CIEL*a*b* system, providing values in the luminosity axis, L*, green-red axis, a*, and in the blue-yellow axis, b*. Over the past decades, CIE developed different formulae for calculating the color alteration (ΔE) of a pair in the L*a*b* coordinates. The most recent methodology is the CIEDE2000 formula, which is considerably more sophisticated than its predecessors CIELAB and CIE94 [5]. This formula has hue weighting functions, an interactive term between chroma and hue differences for improving the performance of blue colors, and a scaling factor for the CIELAB a* axis for improving the performance of gray colors [6]. Previous studies show that CIEDE2000 represents better the color differences perceived by the human eye than the classical CIELAB formula [7, 8]. Nevertheless, CIELAB has also been widely used to color stability evaluation of dental restorative materials due to its simplicity.

The background is defined as the environment of the color element being analyzed, extending for about 10° (observer angle) from it in all or most directions [9]. In addition, the field outside the background is defined as surround [9]. Previous studies have observed that the background color influences the color difference perception [10-12]. Similarly, Wang and Xu [13] found that using a neutral gray background for visual assessments leads to a better performance of CIEDE2000 (less discrepancy between two datasets). Visual color evaluation in Dentistry was demonstrated to not be

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affected if the color evaluation is performed over neutral backgrounds (e.g. white, gray, or black) [14]. On the other hand, the contrast between the sample and the background may affect color perception [15, 16]. Since not all color studies in the dental field are carried out using human visual assessments, CIEL*a*b* parameters and color difference calculations are widely used to study the color alterations of dental restorative materials subjected to aging, staining, or different processing or clinical techniques. Hence, when spectrophotometers or colorimeters are used to obtain the L*a*b* values, the perceptual effect of contrast is absent. However, translucency plays an important role in these measurements since the light reflected by the background partially passes through the sample and is captured by the equipment sensor. In these studies, gray [17-20] and white [21-24] backgrounds are both used for color alteration measurements. Nonetheless, there is a lack of information or data regarding the influence of background on *in vitro* studies using instrumental measurements.

Considering the above context, the present study evaluated how the background (white or gray) affects the color parameters measurements and color difference calculations (ΔE_{ab} or ΔE_{00}) of dental ceramics with different opacities after staining in red wine. The tested hypotheses were that the background color would affect 1) the color difference and 2) L*a*b* parameters, and that 3) L*a*b* alterations after staining would be statistically detected when measured over both white and gray backgrounds.

MATERIALS AND METHODS

Specimen preparation: disc-shaped (Ø12x1.5 mm) samples of a feldspathic ceramic in two shades (Vita VM9, shades EE1 and 3M3, Vita Zahnfabrik, Germany) were prepared (n=20). The two shades were carefully chosen to represent enamel (EE1) and dentin (3M3) opacities. This way, we could understand how the background influences the measurements of translucent and opaque restorative materials. The discs were made into a metallic mold where a 2.0 mm thick ceramic layer was applied. The feldspathic ceramic powder was mixed with the building liquid (Vita VM Modelling Liquid, Vita Zahnfabrik, Germany) to form a slurry. The material was poured into the mold, condensed with manual vibration and the water excess was removed with absorbent paper. The discs were then removed from the mold and placed in a ceramic furnace (Vita Vacumat 6000MP, Vita Zahnfabrik, Germany). The sintering was carried out according to the manufacturer's instructions: pre-heating to 500 °C for 6 min, heating up to 910 °C at 55 °C/min, vacuum during 7 min, cooling down to 800 °C with a closed furnace, to 600 °C with furnace 25% open, and the complete opening of the furnace. This process was repeated one more time for each sample (second firing) to compensate for the ceramic shrinkage. The sintered ceramic discs had both top and bottom surfaces leveled and polished with a sequence of SiC papers to a #1200 grit finishing. Finally, a self-glaze firing was performed in all samples (1 min at 900 °C). One previously trained operator carried out all procedures. A digital caliper (Absolute Digimatic, Mitutoyo, Japan) was used to measure specimens' thickness, and those that varied more than 0.05 mm were discarded. Specimens were lightly marked with a diamond bur on the lateral-bottom surface so that measurements were performed always in the same position. The specimens were kept in dry red wine (Almadén, Miolo, Brazil) for one week aiming to cause color alteration. The ceramic discs were placed separately into plastic containers filled with 5 mL of red wine and kept at 37 °C in a controlled environment during the staining period. The containers were checked every day and refilled up to 5 mL with red wine if evaporation was observed. Color difference can only be calculated when there are at least two L*a*b* measurements (e.g. groups of different shades, before and after aging, or before and after a surface treatment). In this study, we decided to calculate color difference after staining, since it is a widely used methodology in dental studies [20, 24-26]. Red wine was chosen because it is rich in pigments and has been described in previous literature as one of the most staining beverages [25, 26]. The materials used in the study are described in Table I.

Table I - Materials used in the study.

Material	Commercial brand	Manufacturer
Feldspathic ceramic	Vita VM9 shade EE1	Vita Zahnfabrik
Feldspathic ceramic	Vita VM9 shade 3M3	Vita Zahnfabrik
Fermented of cabernet sauvignon grapes	Almadén red wine	Miolo

Color parameters evaluation: color parameters measurements were performed before and after staining in red wine, using a gray background (CIE-L*=50.30, a*=-1.41, b*=-2.37; gray card, Mennon, China) and a white background (CIE-L*=91.27, a*=-1.07, b*=5.38, Cartela Leneta 12H, Cor & Aparência, Brazil). A spectrophotometer SP60 (X-Rite, Grand Rapids, USA) was used for measurements on the analysis mode, D-65 illuminant, 10° observer angle, and CIEL*a*b* color system (Commission Internationale de l'Éclairage). In this system, L* is the luminosity axis with values ranging from 0 (black) to 100 (white), and a* and b* are the color coordinates on the green-red axis and the blue-yellow axis, respectively. A coupling substance (glycerol $C_3H_8O_3$, Vetec Quím. Fina, Brazil) with a refraction index (n) of 1.47 was used to minimize light scattering between the specimen and the background sheet [18]. Firstly, the spectrophotometer was calibrated according to the manufacturer's guidelines. For each specimen, the measurements of L*, a*, and b* coordinates were repeated three times and the average was used for the statistical analysis. The L*, a*, and b* pairs from before and after aging were used to calculate the color alteration with CIEDE2000 (ΔE_{00}, Eq. A) and CIELAB

(ΔE_{ab}, Eq. B) formulae over the gray or white backgrounds:

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

$$\Delta E_{ab}=\sqrt{\Delta L^2+\Delta a^2+\Delta b^2} \quad (B)$$

where ΔL, ΔC, and ΔH are the differences in lightness, chroma, and hue for a pair of samples, and R_T is a rotation function that accounts for the interaction between chroma and hue differences in the blue region. 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', b' coordinates, and the parametric factors k_L, k_C, and k_H are correction terms for deviation from reference experimental conditions. In the present study, these parametric factors of the CIEDE2000 color difference formula were set to 1. And ΔL, Δa, and Δb are differences in L* (luminosity), a* (green-red), and b* (blue-yellow) coordinates, respectively. The CIEL*a*b* measurements were also taken over a black background (L*=27.94, a*=-0.01, b*=0,03; Leneta Card 12H, Cor & Aparência, Brazil). The pair of measurements over the white and the black backgrounds were used for calculating the translucency parameter (TP_{00}) of the specimens with the CIEDE2000 formula (Eq. A). The higher the TP_{00} value the higher the translucency. TP_{00} was acquired previously to the staining so that the translucency of both ceramic shades was estimated for characterization.

Statistical analysis: it was carried out on statistical software (SigmaPlot v.12.0, Systat Software, USA). Data of L*, a*, and b* coordinates before and after aging, and ΔE_{00} and ΔE_{ab} had normality (Shapiro-Wilk test) and homoscedasticity (Levene's test) tested. Then, t-tests were performed to analyze the measurements from gray versus white background (baseline L*a*b*, ΔE_{00}, and ΔE_{ab} data). Baseline versus after staining L*a*b* data were evaluated with paired t-tests to observe if significant differences could be detected in measurements from both white and gray backgrounds. The analyses were performed separately for enamel and dentin ceramic shades. A t-test was also performed to compare the TP_{00} values of dentin and enamel shades. The significance level was set at 5%.

RESULTS

The means and standard deviations of L*a*b* coordinates and color alteration (ΔE_{00} and ΔE_{ab}) of both ceramic shades are described in Table II. Enamel shade results showed that the white background led to higher values of L* and b* coordinates (both $P<0.001$). However, the measurements of a* coordinate were similar over gray and white backgrounds ($P=0.541$), as well as the color difference calculations (ΔE_{00}: $P=0.069$, ΔE_{ab}: $P=0.643$). Regarding the dentin shade, L*a*b* coordinates reached significantly higher values when measured over the white background ($P<0.001$ for all three analyses). Nonetheless, the background did not affect the color difference calculations from CIEDE2000 or CIELAB (ΔE_{00}: $P=0.889$, ΔE_{ab}: $P=0.407$). Statistically significant differences between baseline and after staining L*a*b* coordinates were observed in almost all comparisons from white and gray backgrounds ($P<0.001$, Table III). However, paired t-test pointed out the b* coordinate of the enamel ceramic as statistically similar at baseline and after staining

Table II - Means (standard deviations) of baseline CIE L*a*b* coordinates and the color difference after staining calculated with CIELab (ΔE_{ab}) and CIEDE2000 (ΔE_{00}) equations from measurements over the white and the gray backgrounds.

Opacity	Background	L*	a*	b*	ΔE_{ab}	ΔE_{00}
Enamel	White	70.61 (0.82)^a	-0.76 (0.15)^a	2.39 (0.22)^a	2.62 (0.56)^a	2.11 (0.45)^a
	Gray	57.78 (0.39)^b	-0.79 (0.11)^a	-1.61 (0.15)^b	2.54 (0.36)^a	2.37 (0.33)^a
Dentin	White	74.08 (0.79)^a	5.26 (0.13)^a	25.35 (0.62)^a	2.91 (0.51)^a	2.17 (0.39)^a
	Gray	68.99 (0.66)^b	2.59 (0.08)^b	19.89 (0.57)^b	2.76 (0.54)^a	2.19 (0.42)^a

Different letters within a column indicate statistical differences (white versus gray backgrounds) separately for enamel and dentin ceramic shades (t-tests, P<0.05).

Table III - Means (standard deviations) of baseline CIE L*a*b* coordinates from measurements over the white and gray backgrounds, comparing baseline and after staining data of each ceramic shade.

Opacity	Measurement	White background			Gray background		
		L*	a*	b*	L*	a*	b*
Enamel	Baseline	70.61 (0.82)^a	-0.76 (0.15)^a	2.39 (0.22)^a	57.78 (0.39)^a	-0.79 (0.11)^a	-1.61 (0.15)^a
	Staining	68.04 (0.78)^b	-0.33 (0.20)^b	2.33 (0.16)^a	55.26 (0.39)^b	-0.55 (0.13)^b	-1.52 (0.13)^b
Dentin	Baseline	74.08 (0.79)^a	5.26 (0.13)^a	25.35 (0.62)^a	68.99 (0.66)^a	2.59 (0.08)^a	19.89 (0.57)^a
	Staining	71.26 (0.81)^b	5.54 (0.21)^b	24.90 (0.74)^b	66.29 (0.71)^b	2.75 (0.24)^b	19.47 (0.52)^b

Different letters within a column indicate statistical differences (baseline gray staining data) separately for enamel and dentin ceramic shades and backgrounds (paired t-tests, P<0.05).

when measured over a white background (P=0.201), and statistically different when measured over gray background (P<0.001). Samples made with the dentin shade showed translucency of 8.8 (SD 0.74), and the enamel samples reached 26.1 (SD 1.05), which was significantly different (P<0.001).

DISCUSSION

The background color influenced the L*a*b* measurements of dentin and L*b* measurements of enamel ceramic shades. However, it has not affected the color difference results obtained from any of the materials. This led to the rejection of the first tested hypothesis and the acceptance of the second one. The L*a*b* values were up to ~50% higher for dentin shade (a*) and ~60% for enamel shade (b*) on the white background than over the gray background. Optical properties such as reflectivity and color may significantly influence color measurements when using a solid background [27]. Since the reflectance of white objects is far greater, measurements of the ceramic samples over it seemed to have suffered the influence of background lightness. Fig. 1 shows how the samples' color change over the gray and white backgrounds and it evidences the lightness effect. Besides lightness (L*), the dentin, which is a yellow-reddish shade, also showed a significant change in a* and b* coordinates (Table II). The enamel, which has a grayish shade, presented similar values of a* coordinate over both backgrounds, however, the greatest dataset alteration was observed in its b* coordinate.

The color coordinates (L*a*b*) are a translation of the physical measurements from the spectrophotometer, while the color difference is the mathematical distance between two measurements in a color space. As evidenced in our results, the background color directly affects the spectrophotometer measurement. However, it affects the measurements uniformly as if making an offset on all L*a*b* coordinates. Thus, this 'offset' is sustained even if the coordinates change, i.e. after the specimen were stained. In reason of this equal offset to all coordinates, the ΔE results were statistically similar when calculated from either white or gray backgrounds. Despite color difference calculations were not significantly affected by the background, the coefficient of variation was observed to be higher on the white background of enamel shade ($\Delta E_{abwhite}$=21.4, ΔE_{abgray}=14.2, and $\Delta E_{00white}$=21.3, ΔE_{00gray}=13.9), which indicated a higher data scattering. Nevertheless, the coefficient of variation had less variability in the dentin shade ($\Delta E_{abwhite}$=17.5, ΔE_{abgray}=19.6, and $\Delta E_{00white}$=18.0, ΔE_{00gray}=19.1). Higher scattering was also observed on L* and a* data of the enamel shade (coefficients of variation: L^*_{white}=1.16, L^*_{gray}=0.67, and a^*_{white}=19.73, a^*_{gray}=13.92). Besides the data scattering differences, the gray background led to alteration on b* coordinate due to staining to be statistically detected, while no significant difference was observed from white background measurements (Table III). This was only noticed in the enamel ceramic shade. The enamel was far more translucent (TP_{00}=26.1) than the dentin (TP_{00}=8.8) shade and hence was expected to be more affected by the background choice. In addition, the 50% middle gray, such as the background used in this study, was a color without hue nor chroma and was in the midway of the L* axis. Thus, it was believed to have the least amount of influence on the measurements [19] and produced less scattering among the highly translucent samples.

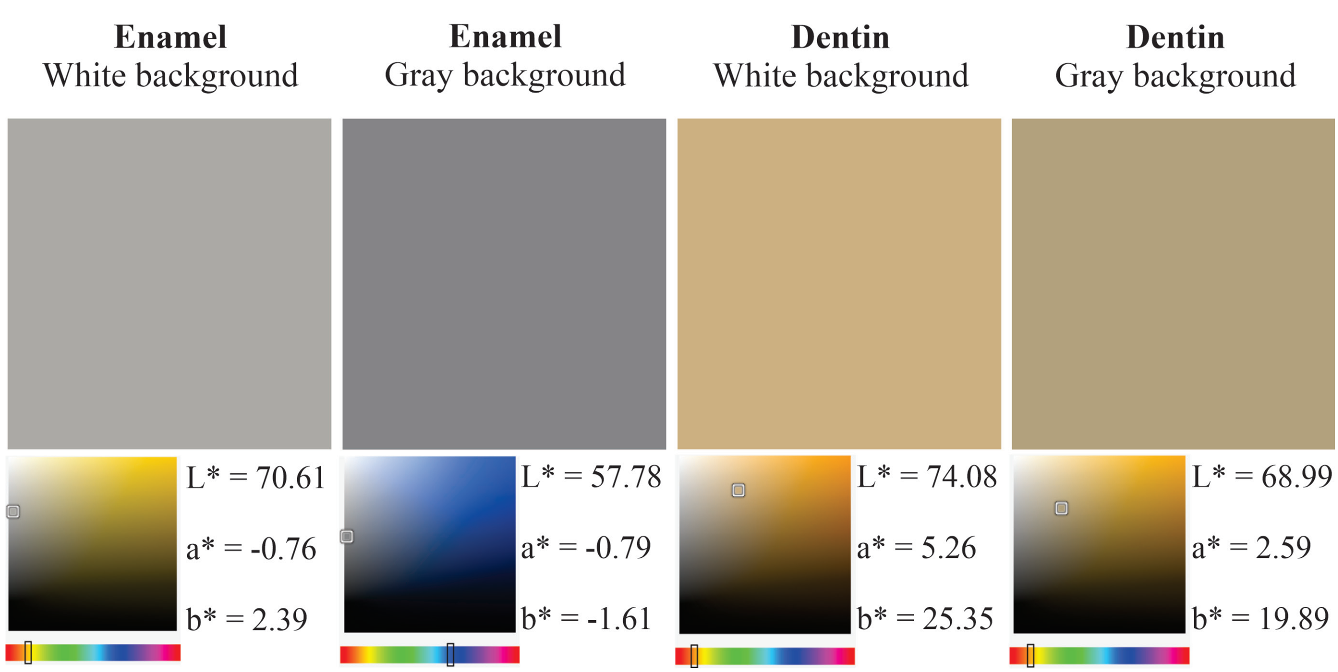

Figure 1: Image prepared on an editing software (CorelDRAW, Corel, Canada) using the average of the initial L*a*b* coordinates of both ceramic shades measured over the white and gray backgrounds. It highlights that the main background effect on the resulting color was in the lightness (L*) for both shades. Also, an important change in b* is observed, especially in the enamel shade.

A recent study reported that the background color affects the perceptibility and acceptability thresholds in visual assessments [28]. The authors found that a color mismatch is more difficultly accepted when observed over a white background. It is discussed that, since white has a higher reflectance value than gray and black backgrounds, it enhances color difference perceptions, which could be clinically helpful in challenging dental shades matching [28]. On the other hand, the influence of background on instrumentally obtained color coordinates of dental restorative materials is little explored [27, 29]. Lee et al. [27] reported that a light trap can eliminate the influence of background variations and the color of the material itself could be more accurately obtained. However, most of the published studies on color evaluation of dental materials are performed with background sheets [17-24]. Thus, there is still a lack of information about handling laboratory color measurements to perform accurate studies and ultimately estimate the clinical behavior of composites and ceramics regarding color stability. Literature shows that the thickness of specimens also influences color measurements [30]. In a study evaluating the masking properties of dental ceramics, Soim et al. [31] observed that highly translucent materials, such as feldspathic ceramics, are extremely susceptible to the background color. In addition, Kamishima et al. [32], in a study with resin composites, observed that only the 4 mm thick samples were not influenced by color backgrounds. However, when a color change of restorative materials is studied, the thickness of full crowns or veneer restorations are usually taken as reference, which ranges from 0.5 to 2.2 mm. For this reason, the thickness used in specimens of this study was 1.5 mm, which is in the thickness range used in previous studies [21, 33-36].

Restorative materials, as dental ceramics, allow some light passage due to their translucency, and consequently are always influenced by the background at some point. Despite the translucency, color alteration studies on dental ceramics are vital for predicting the clinical behavior of these materials. Therefore, information about how to handle its translucency and perform the color measurements in the best way possible is paramount for researchers. Our results showed that if only the color difference is analyzed, measuring the L*a*b* coordinates over a white background should not affect the ΔE results calculated with either CIELAB or CIEDE2000. One should note that this study was performed with small differences (~3 CIELAB units) [10, 13] and, generally, dental ceramics tend to also result in small color differences after staining [24, 36]. However, other restorative materials or treatments may produce a greater color difference. Thus, more studies are encouraged to further investigate if the background would affect differently the calculations of color alteration in large differences. The present study used staining with red wine to produce some color alteration and allow color difference calculations. This method was chosen because the color stability of restorative materials towards staining agents is a concern in Dentistry. Previous studies have shown that even dental ceramics are prone to color alteration by staining [24-26]. However, the color difference can be calculated from other situations that restorative materials are subjected to, such as thermal [21, 37] or surface treatments [38]. Even though our conclusions might be cautiously inferred for color difference analyses other than by staining, more studies on this topic (background effect) are encouraged.

CIEDE2000 has been cited as the most accurate formula for color difference calculations [5, 7, 8] and one of the reference conditions described in its official technical report [39] is the use of a neutral gray (L*=50) background color for visual assessments. Moreover, the standard values that are typically used as visual thresholds to evaluate color differences in Dentistry were acquired with a gray background [40, 41]. Considering this, using a gray background for instrumental measurements would be lined up with the recommendations for visual assessments and with the clinical thresholds. Furthermore, our results point to the recommendation of a neutral gray background to reduce data scattering and avoid non-detection of differences in highly translucent materials when L*a*b* coordinates are analyzed separately. Nonetheless, the background sheet color might not be vital when only ΔE is needed and for small color alterations.

CONCLUSIONS

Background color did not affect the color difference results (CIEDE2000 and CIELAB) of the slightly stained feldspathic ceramic samples from enamel and dentin shades. However, the L*a*b* coordinates values were affected by the background color. A higher data scattering was observed when enamel shade ceramic samples were measured on the white background. Therefore, the use of a gray background is preferable when evaluating highly translucent materials, especially when L*a*b* coordinates are individually analyzed.

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