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RESEARCH ARTICLE

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Is it possible to determine the optical properties of resin composites with clinical spectrophotometers?

Karla Danielly Alves Soares[1] | **Rafaella Mariana de Bragança**[1] | **Pollyana Caldeira Leal**[1] | **Luis Felipe Jochims Schneider**[2] | **André Luis Faria-e-Silva**[1]

[1]Graduate Program in Dentistry, Federal University of Sergipe, Aracaju, Brazil

[2]School of Dentistry, Federal Fluminense University, Niterói, Brazil

Correspondence
André Luis Faria-e-Silva, Graduate Program in Dentistry, Federal University of Sergipe, Rua Cláudio Batista s/n – Sanatório, Aracaju, SE, 49060-100, Brazil.
Email: fariaesilva.andre@gmail.com

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Abstract

The present study aimed to determine how spectrophotometer type and background blackness affect the optical evaluation of resin composites. Cylindrical specimens were built using one resin composite, provided with translucencies named Effect, Enamel, Body, and Dentin ($n = 3$). The CIELAB color coordinates were assessed over black and white backgrounds using a handheld spectrophotometer designed for laboratory readings (SP60, X-Rite) and a spectrophotometer designed for clinical application (Easyshade V5, Vita Zahnfabrik). The black portion of a grayscale target (ColorChecker) and the black trap portion of the calibration reference of the spectrophotometer were used. Color differences between the devices were calculated, as well as the translucency parameter and contrast ratio. Data were analyzed by repeated-measures ANOVA and linear regressions ($\alpha = .05$). In general, Easyshade resulted in higher values for all color coordinates than the SP60, irrespective of the background. Easyshade was unable to measure the color of composite Effect over black backgrounds. For other composite translucencies, both spectrophotometers yielded similar values of translucency parameter and contrast ratio, and the blackness of the black background did not affect these results. The highest agreement for the translucency parameter and contrast ratio values was observed for the composite Dentin. High agreement was observed between the two spectrophotometers regarding the translucency parameter and contrast ratio values. However, the clinical spectrophotometer was unable to measure the color of the more translucent composite over a black background and overestimated the color coordinates.

KEYWORDS

color, esthetic dentistry, opacity, resin composites, spectrophotometer

1 | INTRODUCTION

Overall tooth color results from both the chromaticity and translucency of dentin and enamel, and this combination of optical effects should be considered when selecting restorative materials, in order to obtain more natural restorations.[1-3] The measurement of translucency (or opacity) of resin composites is important for informed decisions about their use to replace dentin or enamel in restorative dentistry. Such measurements have been undertaken using various methods, but with questionable validity.[4-9]

Laboratory spectrophotometers have been widely used to characterize the optical properties of restorative materials, especially opacity.[4-6] Opacity is expressed as an index, calculated from the difference between successive measurements against black and white backgrounds. The rationale is that an object must be opaque if the difference between these two measurements is small. However, such equipment is unable to measure the color of teeth or restorative materials under clinical conditions. For this reason, spectrophotometers have been developed specifically for measuring tooth color in dentistry, such as the Vita Easyshade (Vita-Zahnfabrik, Bad Säckinge, Germany).[7-9] The rationale is that a single instrument will suffice for clinical and in-vitro assessments. Although the system is user-friendly, the Easyshade system does not have a specific function to determine opacity. Therefore, the opacity is frequently estimated through the relative translucency parameter (TP) calculated from the overall color difference (ΔE^*_{ab}) between the measurements performed against black and white backgrounds.[7,10,11] However, this parameter is a relative measurement and depends on the subtle color of the "black" and "white" backgrounds, plus additional parameters. Another approach to determine the opacity level of a given material is through a contrast ratio (CR) calculated from spectral reflectance (Y) of the specimens.[12] Despite its popularity, there is a lack of information about whether a spectrophotometer designed for clinical evaluation can accurately and reliably assess the optical features of dental composites

Another important aspect for optical properties' determination is the color of the background used.[13,14] The literature reveals that a wide range of backgrounds has been used because of the difficulty of obtaining true white and true black targets. Furthermore, many reports do properly describe the backgrounds used for determining optical properties. There is thus a need to investigate the extent to which background color affects the values of TP and CR. This study aimed to determine the agreement level between the outcomes obtained with the spectrophotometer designed for clinical application—Vita Easyshade—with those from a laboratory spectrophotometer. Furthermore, the effects of different composite translucencies and black backgrounds on color coordinates, CR and TP values were also evaluated. The research hypotheses were that:

1. The optical properties obtained using a clinical spectrophotometer differ from those obtained with a laboratory spectrophotometer.
2. The blackness of the background influences the outcomes.

2 | MATERIAL AND METHODS

2.1 | Experimental design

This was a laboratory study evaluating how the independent variables "spectrophotometer" (two levels), "resin composite translucency" (four levels), and "black background" (two levels) affect the dependent variables TP and CR. Four levels of resin composite translucencies were used: Effect, Enamel, Body, and Dentin (Forma, Ultradent, Indaiatuba, SP, Brazil). Except for the Effect translucency, which used the shade Transparent, all the other translucencies were from the shade designated A2 in the Vita Classical shade guide (Vita-Zahnfabrik, Bad Säckinge, Germany). CIELAB color coordinates of specimens were measured with the spectrophotometers SP60 (X-Rite, Grand Rapids, MI) and Easyshade (Easyshade Compact V5, Vita-Zahnfabrik). The black backgrounds used were the black portion of the ColorChecker Grayscale (X-rite) target and the black trap portion of the calibration referent of the SP60 spectrophotometer.

2.2 | Sample size calculation

Sample size calculation was performed for the dependent variable TP and 16 experimental conditions ($4 \times 2 \times 2$). The acceptability threshold of 4.4[15] was used as the minimum detectable difference in means, and the averaged standard deviation (0.79) from a prior study that calculated TP of resin composites.[16] Therefore, three specimens per experimental condition were required to achieve an 80% probability of detecting this difference as being significant at a level of 95%.

2.3 | Specimen preparation

Disk-shaped specimens were built up by inserting a single composite increment into a rubber matrix ($\varnothing = 20$ mm, $h = 1.6$ mm), placed between polyester strips. The composite was light-cured using the LED-based Optilight Max unit (tip irradiance ≈ 1130 mW/cm^2; Gnatus, Barretos, SP, Brazil) with four 40-second periods of photoactivation with the light unit positioned approximately 2 mm from the surface, for a total of 160 s of photoactivation ($n = 3$). The light-curing unit tip (internal $\varnothing \approx 7.4$ mm) was moved between each photoactivation period to cover the entire specimen surface in overlapping positions. The specimen thicknesses were measured with digital calipers in three different positions across the specimen. The specimens were stored in a dry environment for 24 hours before their optical properties were measured.

2.4 | Color coordinates

The CIELAB color coordinates of all the specimens were measured placing the specimens over the following backgrounds:

1. the white portion of the ColorChecker Grayscale target ($L^* = 92.6$; $a^* = 1.0$, and $b^* = -0.5$),
2. the black portion of the ColorChecker Grayscale target ($L^* = 32.6$; $a^* = 1.1$, and $b^* = 3.5$), and
3. the black trap portion of the calibration reference of the spectrophotometer SP60 ($L^* = 0.2$; $a^* = 0.1$, and $b^* = -0.2$).

The integrated sphere-based SP60 spectrophotometer was used in reflectance mode with illuminant D65 and the 2° observer function for specimens and background color readings. Since Easyshade is a portable spectrophotometer developed for clinical assessment of tooth and restoration color, it works only with illuminant D65 and the 2° observer. This standardization of the 2° observer function under illuminant D65 defines the color space and the color measured. All readings were performed in triplicate, no optical solution was placed between the specimen and backgrounds, and data were recorded according to the CIELAB system in which L^* indicates the sample's lightness, and the chromaticity coordinates a^* and b^* are measured on the red-green and yellow-blue axes, respectively.[17,18]

2.5 | Color difference between spectrophotometers

For each background, the overall color difference measured between the spectrophotometers was calculated using the following formula (19):

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

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are the differences in lightness, chroma, and hue, respectively. The values S_L, S_C, and S_H are the weighting functions for each component. R_T is the interaction term between the chroma and hue differences.

2.6 | Translucency parameter

The values were calculated from the overall color difference measured between the white and black backgrounds. For example, as the TP was calculated from color measured over two different black backgrounds, using two spectrophotometers, there were four TP values per sample. The TP was calculated using the same formula as used for ΔE_{00}.

2.7 | Contrast ratio

The luminance (Y) from the CIEXYZ system was calculated using L^* values as follows (12):

$$Y = \left(\frac{L+16}{116}\right)^3 \times Y_n \tag{2}$$

where Y_n was defined as equal to 100.0.[17] Therefore, the CR of specimens was defined by the ratio between the luminances calculated for white and black backgrounds:[12]

$$\mathrm{CR} = \frac{Y_{\mathrm{white}}}{Y_{\mathrm{black}}} \tag{3}$$

TP and CR were estimated using measurements on the aforementioned axes, using both spectrophotometers over white and two black backgrounds (black portion of Color Checker, and the black trap of the spectrophotometer SP60 calibration referent), resulting in four values of each parameter.

2.8 | Statistical analysis

The overall color differences (ΔE_{00}) were analyzed by repeated-measures ANOVA, with "composite translucency" and "black background" as repetition factors. The means of the color differences were compared to the acceptability ($\Delta E_{00} = 1.8$) and perceptibility ($\Delta E_{00} = 0.8$) thresholds.[20] Linear regression analyses were carried out to verify the correlation between measurements obtained with the SP60 (defined as a response variable) and those with the Easyshade, for each color coordinate as well as variations on these values. The regression analyses were split by either "composite translucency" or "black background."

The calculated TP and CR were submitted to repeated-measures ANOVA entailing the factors "composite translucency," "black background," and "spectrophotometer." The two last factors were selected as repetition factors. The level "Effect" was removed from the factor "composite translucency" since it was not possible to read its coordinates over the two black backgrounds when using the Easyshade. Further, another repeated-measures ANOVA was carried out for each outcome without the factor "spectrophotometer," allowing to include the level

"Effect" with the factor "composite translucency." This last analysis aimed to assess a possible interaction between "composite translucency" and "black background" in the results. Since ANOVA does not specify which specific group's means are different, pairwise comparisons were performed using the Tukey's test, which compare all possible pairs of means.

For each outcome, linear regression analyses were carried out to assess the strength of correlations between measurements using the SP60 (defined as response variable) and those obtained with the Easyshade. Regression analyses were split by either "composite translucency" or "black background." Moreover, linear regression analyses were performed to investigate correlations between the different outcomes calculated, with a pre-set significance level of 95%.

3 | RESULTS

3.1 | Color coordinates

Figure 1 presents the color coordinates measured for each experimental condition. In general, lower lightness values (L^*) were observed for measurements made with the SP60 than with the Easyshade. Each device measured the highest lightness for the white background, and vice versa with the two black backgrounds. Differences

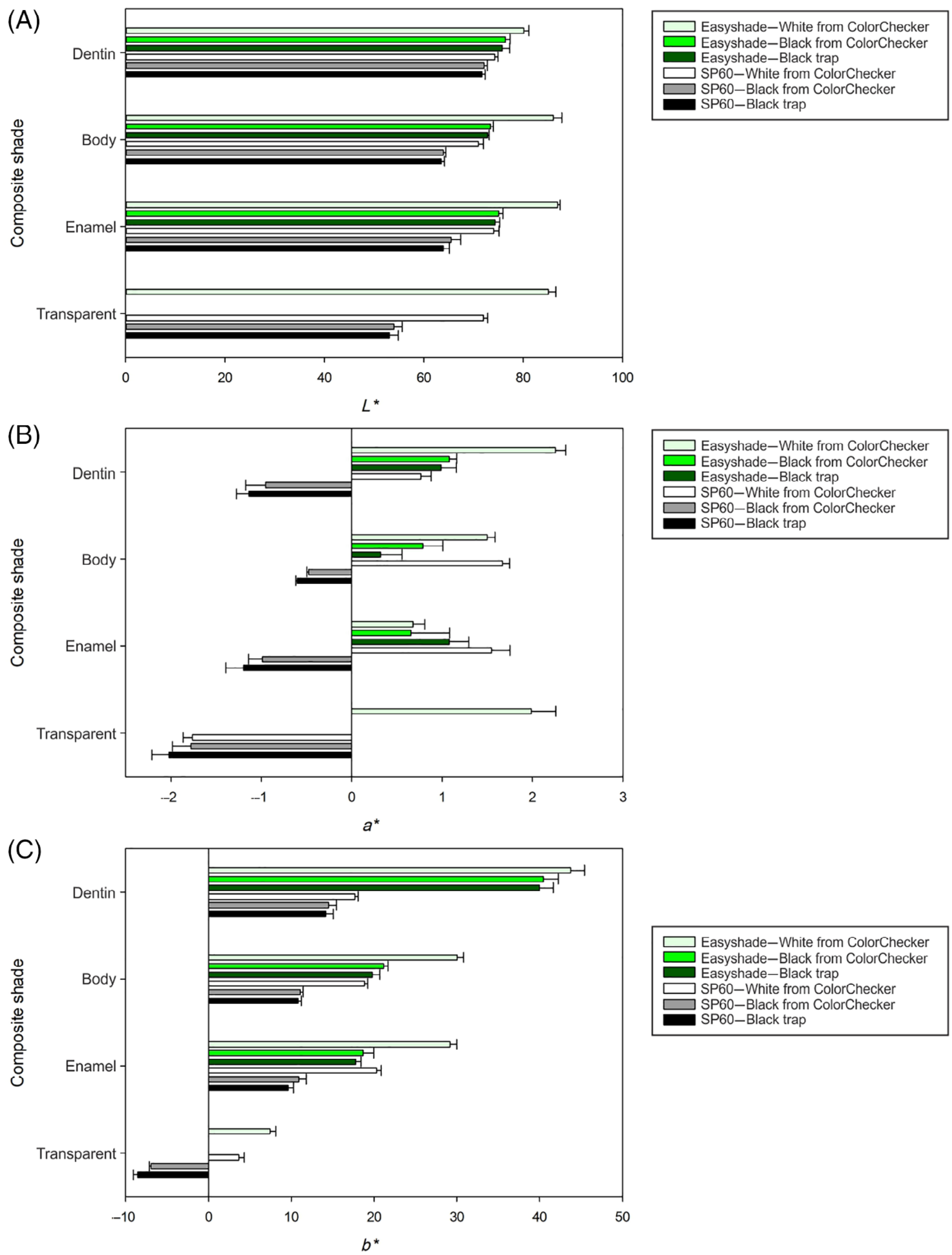


FIGURE 1 Means (standard deviations) of color parameters according to composite shade, spectrophotometer, and background. (A) Lightness (parameter L^*); (B) red-green axis (parameter a^*); and (C) yellow-blue axis (parameter b^*)

between measurements against each background tended to reduce from the resin composite Transparent (more translucent) toward Dentin (opaquer). The highest red-green values (a^*) were observed using the Easyshade on resin composites Transparent and Dentin against the white background. In contrast, the SP60 measured in higher redness over the white background than did the Easyshade for translucencies Enamel and Body. The highest redness was observed over the white background. Except for measurements of Enamel with the Easyshade, the black trap tended to result in slightly lower yellowness than the black portion of ColorChecker. On the blue-yellow axis (b^*), a tendency was observed for increasing yellowness from the black trap toward the white background using both devices. The Easyshade measured higher yellowness than did the SP60. The lowest values of b^* were measured on the translucency Transparent, and the highest for Dentin.

3.2 | Color difference between spectrophotometers

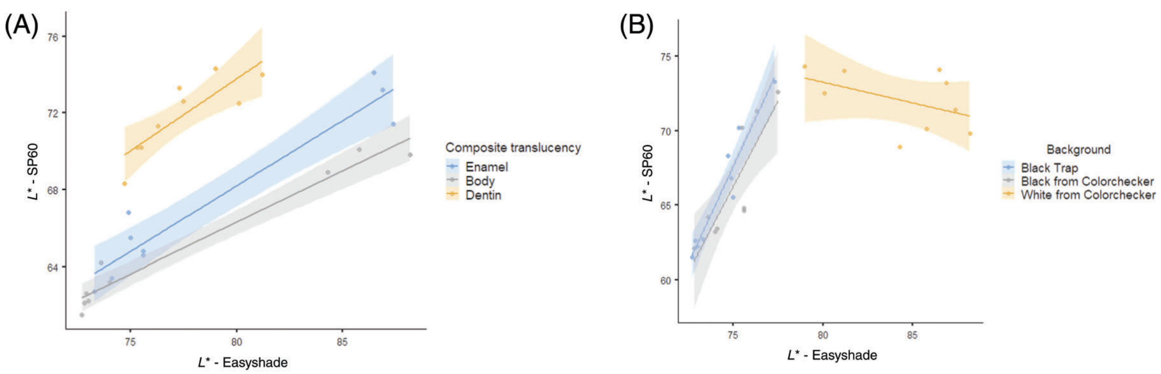
Repeated-measures ANOVA showed that both "composite translucency" ($P = .013$) and "spectrophotometer" ($P = .013$) affected ΔE_{00}, and interaction between the factors was also significant ($P = .003$). Except for the white background (which produced no differences among the translucencies), the highest color differences were observed for the Dentin without difference between the other composite translucencies (Table 1). For Dentin and Enamel, the background did not affect ΔE_{00}. On the other hand, using the white background yielded the highest values of ΔE_{00} for the Body, and no difference was found between the two black backgrounds.

Linear regressions analyses between SP60 and Easyshade color measurements are presented in Figures 2–4. Regarding the lightness (L^*), the coefficients of determination were higher than .9 for both Enamel and Body, and lowest for Dentin. A low concordance between the spectrophotometer in lightness values was observed when the readings were performed against the white background. For the red-green coordinate (a^*), R^2 was extremely low for Enamel, and when the color was measured over the ColorChecker black background. The highest coefficient of determination was observed for Dentin. In general, the highest coefficients of determination were observed for the yellow-blue coordinate (b^*).

TABLE 1 Means (standard deviation) of ΔE_{00} calculated by difference between the color measured with SP60 and Easyshade according to composite translucencies and backgrounds used (n = 3)

Composite translucency		Enamel	Body	Dentin
Background	Black trap	9.3 (1.3) Ab	10.5 (0.4) Bb	12.5 (0.8) Aa
	Black from ColorChecker	10.1 (0.3) Ab	10.1 (0.5) Bb	12.3 (0.5) Aa
	White from ColorChecker	10.8 (1.3) Aa	12.8 (0.9) Aa	11.6 (0.3) Aa

Note: Distinct letters (uppercase comparing backgrounds, lowercase comparing composite translucencies) indicate statistical difference at Tukey's test ($P < .05$).



Enamel: $y = 13.91\ (6.07) + 0.68\ (0.08)^* x$; $R^2 = .918$

Body: $y = 23.54\ (3.24) + 0.54\ (0.04)^* x$; $R^2 = .959$

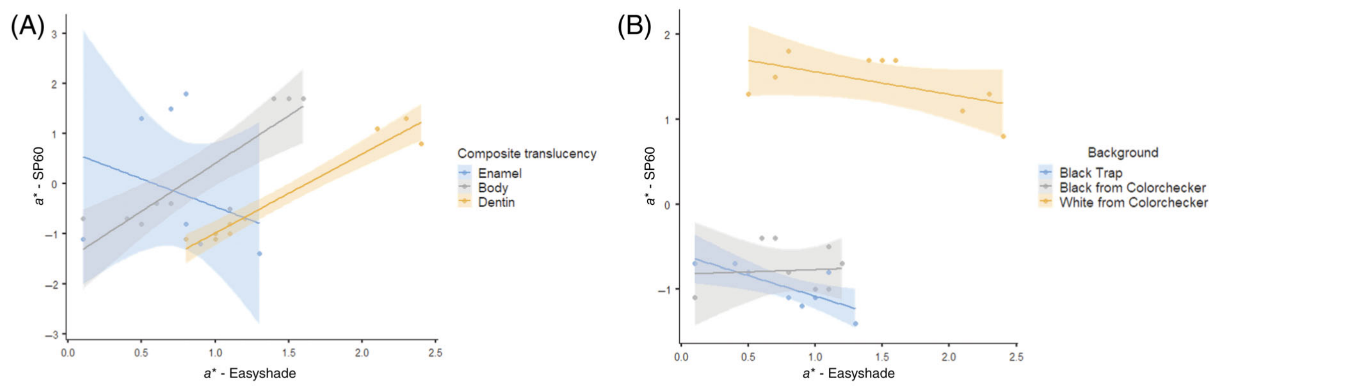
Dentin: $y = 13.88\ (13.88) + 0.75\ (0.18)^* x$; $R^2 = .714$

Black trap: $y = -127.66\ (21.63) + 2.60\ (0.29)^* x$; $R^2 = .920$

Black from ColorChecker: $y = -105.69\ (38.91) + 2.29\ (0.52)^* x$; $R^2 = .736$

White from ColorChecker: $y = 95.44\ (16.97) - 0.28\ (0.20)^* x$; $R^2 = .214$

FIGURE 2 Linear regressions analyses for values of Lightness (L^*) obtained using SP60 (y) and Easyshade (x). Regressions were split as a function of composite translucency (A) or background (B)



Enamel: $y = 0.65\ (1.21) - 1.11\ (1.42)^* x; R^2 = .081$

Body: $y = -1.50\ (0.37) + 1.91\ (0.36)^* x; R^2 = .800$

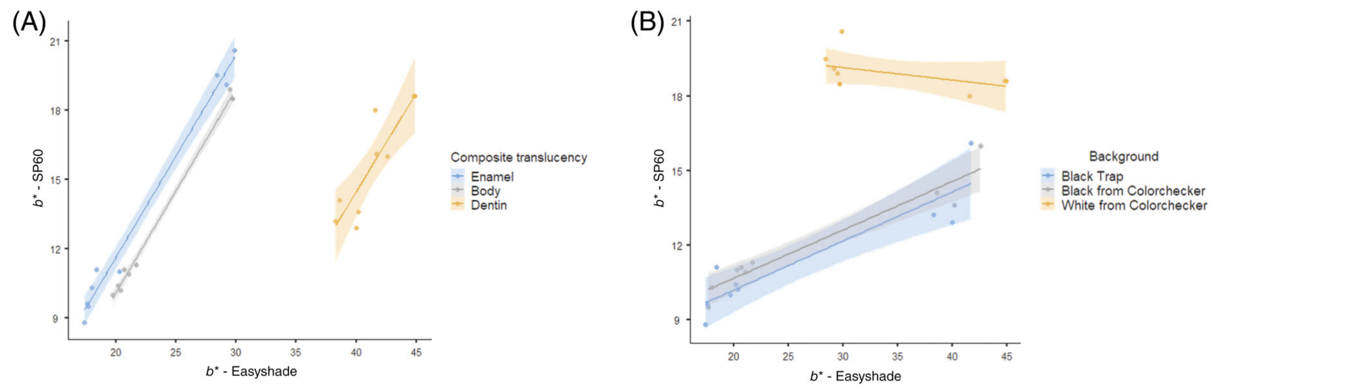
Dentin: $y = -2.56\ (0.22) + 1.58\ (0.14)^* x; R^2 = .947$

Black trap: $y = -0.60\ (0.14) - 0.49\ (0.16)^* x; R^2 = .580$

Black from ColorChecker: $y = -0.82\ (0.29) + 0.05\ (0.32)^* x; R^2 = .004$

White from ColorChecker: $y = 1.87\ (0.24) - 0.27\ (0.15)^* x; R^2 = .312$

FIGURE 3 Linear regressions analyses for values of parameter a^* (red-to-green axis) obtained using SP60 (y) and Easyshade (x). Regressions were split as a function of composite translucency (A) or background (B)



Enamel: $y = -5.96\ (0.90) + 0.88\ (0.04)^* x; R^2 = .986$

Body: $y = -7.57\ (0.55) + 0.88\ (0.02)^* x; R^2 = .995$

Dentin: $y = -19.82\ (7.09) + 0.86\ (0.17)^* x; R^2 = .782$

Black trap: $y = 6.24\ (0.92) + 0.20\ (0.03)^* x; R^2 = .837$

Black from ColorChecker: $y = 6.70\ (0.60) + 0.20\ (0.02)^* x; R^2 = .925$

White from ColorChecker: $y = 20.65\ (1.21) - 0.05\ (0.04)^* x; R^2 = .233$

FIGURE 4 Linear regressions analyses for values of parameter b^* (yellow-to-blue axis) obtained using SP60 (y) and Easyshade (x). Regressions were split as a function of composite translucency (A) or background (B)

3.3 | Translucency parameter

Figure 5A shows the means and standard deviations for TP according to the independent variables analyzed. Repeated-measures ANOVA showed that "composite translucency" ($P < .001$), "black background" ($P = .007$), and "spectrophotometer" ($P = .050$) affected the TP values. The interactions "composite translucency versus black background" ($P = .246$) and "black background versus spectrophotometer" ($P = .083$) were not significant. On the other hand, the interactions "composite translucency versus spectrophotometer" ($P = .017$) and "composite translucency versus spectrophotometer versus black background" ($P = .010$) were significant. Higher TP values were calculated based on colors measured with Easyshade than those obtained by using SP60 only for the Dentin (Table 2). For both spectrophotometers, Dentin had the lowest TP values, and no difference was observed between Enamel and Body. The highest TP values (measured only with SP60) were observed for the composite Effect.

Excluding the factor "spectrophotometer" from analysis, repeated-measures ANOVA showed that both "composite translucency" ($P < .001$) and "black background" ($P < .001$) affected the TP values, and the interaction between the factors was also significant ($P = .007$). Irrespective of the black background used, the highest and lowest TP values were observed for the translucencies Effect and Dentin, respectively (Table 3). No difference was observed between Enamel and Body. The black background affected the TP values only for the composites Effect and Body, and the highest values were observed when the black trap was used.

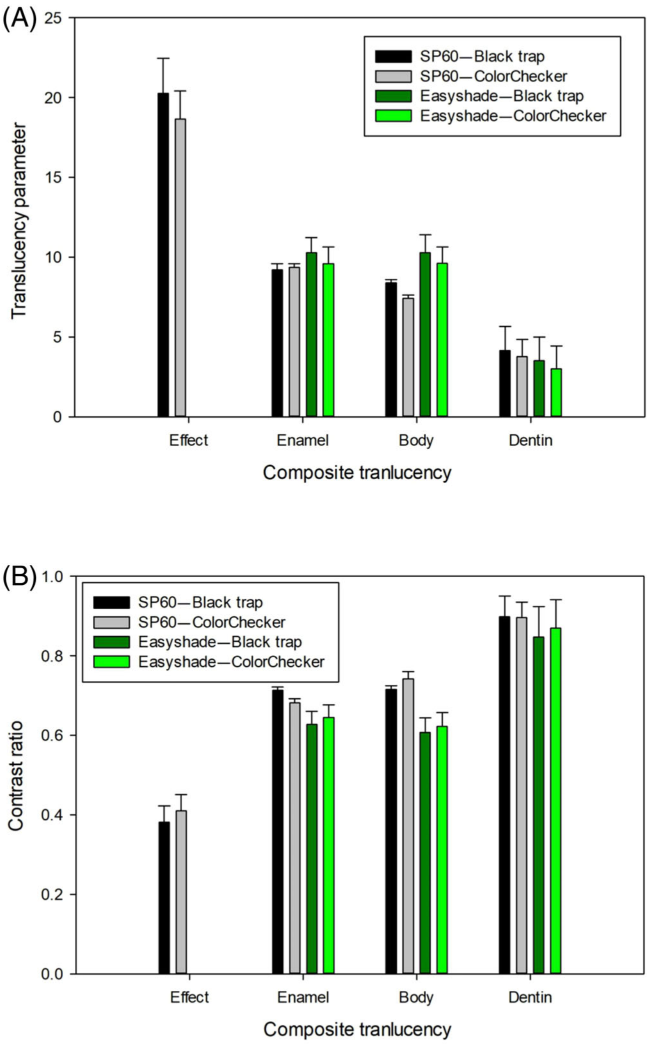


FIGURE 5 (A) Means (standard deviation) of Translucency parameter and (B) Contrast ratio according to spectrophotometer, black background and composite translucency

Results of linear regression analysis to assess the correlation between TP values from SP60 and Easyshade measurements are displayed in Figure 6. Similar coefficients and a high correlation were observed for both black backgrounds, and only Dentin presented a high R^2 value when the regression was split according to the composite translucency.

3.4 | Contrast ratio

Figure 5B presents the mean CRs and their standard deviations according to the independent variables analyzed in the study. Repeated-measures ANOVA showed that both "composite translucency" ($P < .001$) and "spectrophotometer" ($P < .001$) affected the CR, but not the "black background" ($P = .129$). The interactions "composite translucency versus spectrophotometer" ($P = .102$) and "composite translucency versus black background" ($P = .102$) were not significant. On the other hand, the interactions "black background versus spectrophotometer" ($P = .008$) and "composite translucency versus spectrophotometer versus black background" ($P = .008$) were significant. Table 2 shows that, regardless of composite translucency, higher CR values were observed for SP60 measurements than for Easyshade measurements. Enamel and Body had similar contrast rations that were lower than those observed for Dentin. The composite Effect presented the lowest CR (measured only with the SP60).

Analysis without the factor "spectrophotometer" found that only the "composite translucency" ($P < .001$) affected the CR values. Both "black background" ($P = .067$) and the interaction between the factors ($P = .168$) were not significant. For each spectrophotometer, Enamel and Body had similar CR, which were lower than the CR calculated for Dentin (Table 2).

TABLE 2 Pooled average means (standard deviation) of TP and CR, combining data from both black backgrounds, according to composite translucency and spectrophotometer (n = 6)

Outcome		**TP**		**CR**	
Spectrophotometer		**SP60**	**Easyshade**	**SP60**	**Easyshade**
Composite translucencies	Effect[a]	19.5 (2.0) A	N/A	0.40 (0.04) C	N/A
	Enamel	9.3 (0.3) Ba	9.9 (1.0) Aa	0.70 (0.02) Ba	0.64 (0.03) Bb
	Body	7.9 (0.6) Bb	9.8 (1.0) Aa	0.73 (0.02) Ba	0.61 (0.03) Bb
	Dentin	4.0 (1.2) Ca	3.3 (1.3) Ba	0.90 (0.04) Aa[a]	0.86 (0.07) Ab

Note: For each outcome, distinct letters (uppercase comparing composite translucencies, lowercase comparing spectrophotometers) indicate statistical difference at Tukey's test ($P < .05$).

Abbreviations: CR, contrast ratio; N/A, not available; TP, translucency parameter.

[a]It was not included in repeated measures ANOVA, but it was compared to other levels for SP60 using Tukey's test.

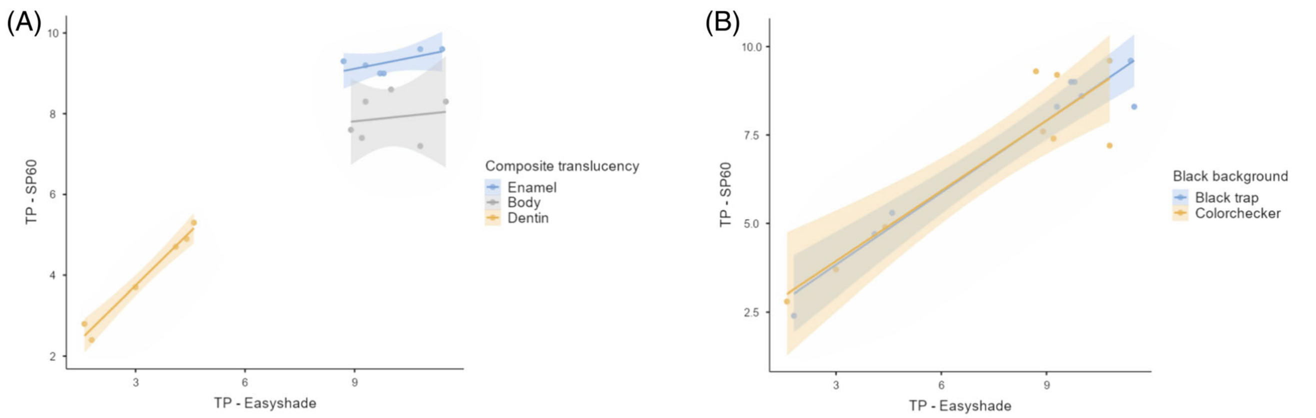
TABLE 3 Pooled average means (standard deviation) of TP and CR, combining data from both spectrophotometers, according to composite translucency and black background (n = 6)

Outcome		TP		CR	
Black background		**Black trap**	**ColorChecker**	**Black trap**	**ColorChecker**
Composite translucencies	Effect[a]	20.3 (2.2) Aa	18.7 (1.8) Ab	0.38 (0.04) Ca	0.41 (0.04) Ca
	Enamel	9.7 (0.9) Ba	9.5 (0.7) Ba	0.67 (0.05) Ba	0.66 (0.03) Ba
	Body	9.3 (1.3) Ba	8.5 (1.4) Bb	0.66 (0.06) Ba	0.68 (0.07) Ba
	Dentin	3.8 (1.4) Ca	3.4 (1.2) Ca	0.87 (0.06) Aa	0.88 (0.05) Aa

Note: For each outcome, distinct letters (uppercase comparing composite translucencies, lowercase comparing black backgrounds) indicate statistical difference at Tukey's test ($P < .05$).

Abbreviations: CR, contrast ratio; TP, translucency parameter.

[a]n = 3.



Enamel: $y = 7.51\ (1.04) + 0.18\ (0.10)^*\ x; R^2 = .425$

Body: $y = 6.97\ (2.76) + 0.09\ (0.28)^*\ x; R^2 = .028$

Dentin: $y = 1.09\ (0.26) + 0.89\ (0.07)^*\ x; R^2 = 972$

Black trap: $1.80\ (0.56) + 0.68\ (0.06)^*\ x; R^2 = .940$

ColorChecker: $y = 1.95\ (0.89) + 0.66\ (0.11)^*\ x; R^2 = .838$

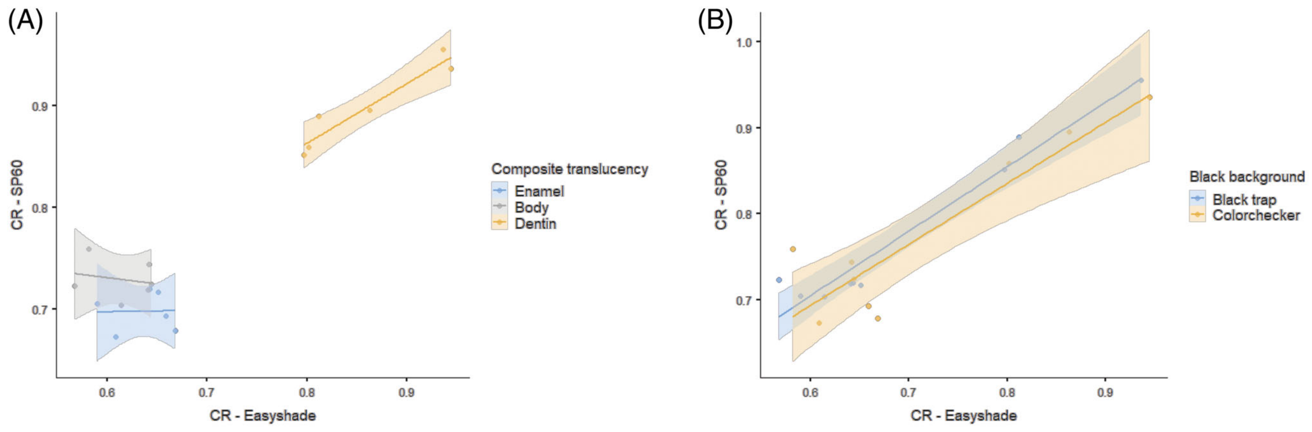
FIGURE 6 Linear regressions analyses for values of translucency parameter (TP) calculated using SP60 (*y*) and Easyshade (*x*). Regressions were split as a function of composite translucency (A) or black background (B)

Figure 7 presents the results of linear regression analyses carried out to assess a possible correlation between CRs obtained with SP60 and those from Easyshade. The composite translucency significantly affected the correlation between the CR values obtained with the different spectrophotometers, and a high correlation was observed only for Dentin.

4 | DISCUSSION

The difference between the color measured using the clinical spectrophotometer Easyshade and those recorded with the spectrophotometer SP60 (ΔE_{00} ranged from 9.3 to 12.8) far exceeded the 50:50% acceptability threshold (ΔE_{00} = 1.8) calculated in a prior study.[20] It means that significantly different colors were read by each device. Furthermore, the clinical spectrophotometer did not allow determination of CR and TP for the Effect composite, leading to rejection of our first hypothesis. The difference between the two devices was more pronounced for the opaquest composite (Dentin), and the background did not affect the overall color difference. As expected, the background has a higher effect when measuring the color of more translucent specimens. Regarding the highest values of ΔE_{00} for the white background, the increased overall color difference follows the tendency of higher values in all color coordinates when this background was used. In contrast, ΔE_{00} for the composite Dentin was related to increased values observed in the chromatic coordinates, but in lightness.

Despite the different values, high direct correlations (R^2 ranged from .71 to .99) were observed for data of both L^* and b^* between the two spectrophotometers evaluated, regardless of the composite translucency (Effect composite was excluded from analyses). On the other hand, an



Enamel: $y = 0.69\ (0.20) + 0.02\ (0.32)^*\ x; R^2 < .001$

Body: $y = 0.81\ (0.18) – 0.12\ (0.29)^*\ x; R^2 = .044$

Dentin: $y = 0.39\ (0.08) + 0.59\ (0.09)^*\ x; R^2 = .906$

Black trap: $y = 0.26\ (0.05) + 0.75\ (0.07)^*\ x; R^2 = .947$

ColorChecker: $y = 0.27\ (0.09) + 0.71\ (0.13)^*\ x; R^2 = .823$

FIGURE 7 Linear regressions analyses for values of contrast ratio (CR) calculated using SP60 (*y*) and Easyshade (*x*). Regressions were split as a function of composite translucency (A) or black background (B)

extremely low correlation ($R^2 = .08$) for *a** was observed between the two devices when evaluating Enamel composite (more translucent). Moreover, *L** and *b** behaved similarly when the linear regression analyses were split by background, in contrast to what was observed for *a**. For the two former coordinates, a high concordance between the devices occurred when the color readings were carried out over black backgrounds, but R^2 was low when using a white background. Regarding *a**, low concordance was observed regardless of the backgrounds used.

Considering the measurements from the laboratory spectrophotometer as the more accurate, these findings suggest that the Easyshade may have a compromised ability on the red-green axis (*a**), especially when measuring the color of a more translucent composite. Interestingly, extremely low concordance within data from the SP60 was observed for all coordinates when the color was measured over the white background, although the Easyshade was unable to measure the color of the Effect composite over black backgrounds. The Easyshade was developed specifically to read the color of teeth and dental restorations, and thus it is reliable for yellow and yellow-red colors.[21] In fact, data from Easyshade overestimated the redness (increased *a**) and yellowness (increased *b**) of composites compared with the SP60. However, placing the composites over black backgrounds reduced both *a** and *b**, leading to a higher concordance between the spectrophotometers' readings. A further reduction in redness and yellowness was observed toward more translucent composites; and greener and bluer specimens resulting from the Effect composite over the black backgrounds impaired the ability of Easyshade to read the color of this experimental condition. A plausible explanation is that the Easyshade is built with a reduced-range sensor designed for clinical applications and, thus, outcomes taken for laboratory investigations must be carefully considered.

The color reading over black and white backgrounds allows calculation of important optical features of resin composites based on the difference in color coordinates measured against each background. Both TP and CR indicate the ability of an object to prevent the passage of light, estimating the opacity (or translucency) of the composite.[22,23] Therefore, an increase in the color difference is also expected by using backgrounds with an increased color discrepancy between them and, ideally, TP and CR should be calculated from measurements using backgrounds with lightness values of zero (black) and 100 (white), while the other color coordinates should be zero, that is, without any chromaticity. Even though such ideal backgrounds are only theoretical, it is important to use backgrounds that approximate true black and true white as closely as possible when estimating the TP and CR of materials. In the present study, the “white” and “black” parts of a color target designed for color calibration in digital photography were used. Indeed, despite the low chromaticity, the lightness of the ColorChecker white and black referents was not truly white ($L^* \approx 97$) nor black ($L^* \approx 30$). The black trap, however, resulted in an absolute black background since it achieved zero reflectance. Therefore, TP and CR of composites were then calculated using either a true black background or a very dark background presenting some level of residual lightness.

Interestingly, the black background used did not affect the CR, and a statistically significant difference (1.8) was observed in TP only for the composite Effect. However, despite the difference exceeding the 50:50% perceptibility threshold (0.62), the lower TP calculated when the black portion of ColorChecker was used lies within the 50:50% acceptability threshold (2.62).[15] Indeed, high correlation coefficients (R^2 values from .823 to .980) were observed between the CR and TP from Easyshade and SP60 measurements, without a significant effect attributable to the black background. Therefore, the second hypothesis of the study was also rejected. A recent study found similar visual thresholds for TP using either gray ($L^* = 76.1$; $a^* = -0.2$, and $b^* = 1.0$) or black ($L^* = 9.1$; $a^* = -0.1$, and $b^* = -1.3$) backgrounds, demonstrating a non-significant effect of these backgrounds on color perception.[14] In the present study, the black backgrounds used presented similar values for a^* and b^*, and a L^* difference of 32.4; which is approximately half of the difference between the gray and black backgrounds used in that prior study.[13] Similar color coordinates were observed for all composite translucencies in both black backgrounds, confirming the non-significant effect of the blackness of the background.

On the other hand, the use of Easyshade tended to result in lower TP and higher CR than when using the SP60; using the Easyshade tended to underestimate outcomes. The calculation of TP is based on the difference of all color coordinates measured over black and white backgrounds.[10] Linear regression analyses for differences between these backgrounds according to color coordinates show positive Y_0, indicating a tendency of Easyshade to measure higher ΔL^*, Δa^*, and Δb^* than the SP60. On the other hand, only L^* (used to estimate the lightness) is used to calculate the CR values.[12] However, CR increases (opaquer object) as TP decreases.

Despite some differences in values, the ranking of composites translucencies for TP and CR was the same, regardless of the spectrophotometer used. Both devices showed similar opacity (TP and CR) between the translucencies corresponding to Enamel and Body, and the highest opacity for Dentin. However, it is important to emphasize that the Easyshade was unable to measure the color of the composite Effect—and consequently its TP and CR—and a high coefficient of determination between the two devices for TP and CR values was observed only when the opaquer composite (Dentin) was analyzed.

Since most studies on dental materials aim to compare materials, these findings demonstrate that the clinical spectrophotometer may be suitable for estimating some optical properties of composites, despite its limitations assessing the color of more translucent materials over dark backgrounds. A limitation of the present study is that no coupling medium was used for measuring the optical properties, and intermediary air can affect the results.[24] Moreover, other limitations arise from comparing the measurements from a clinical spectrophotometer with those from a single laboratory spectrophotometer. Dissimilar results can be observed with different devices, and the harmonization of color measurements remains a challenge.[25] Therefore, the current findings demonstrate the importance of evaluating the reproducibility of color evaluation using different devices, under different experimental conditions. Moreover, the reliability of using a spectrophotometer designed for clinical purposes to assess the optical properties of dental materials should be further evaluated.

According to the reported outcomes, it is possible to conclude that the Easyshade device is unable to measure the color of the more translucent composite over a black background and that it tends to produce higher values than the laboratory spectrophotometer for all color coordinates. However, measurements from both devices result in a similar estimation of opacity of composites. Also, the blackness of the black background does not significantly affect the estimation of opacity of composites.

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CONFLICT OF INTEREST

The authors do not have any financial interest in the companies whose materials are included in this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

André Luis Faria-e-Silva https://orcid.org/0000-0003-3846-4786

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AUTHOR BIOGRAPHIES

Karla Danielly Alves Soares is a graduate student in the Graduate Program in Dentistry at the Federal University of Sergipe, Aracaju, Brazil. Her thesis is based on the color evaluation of dental composites.

Rafaella Mariana de Bragança is a PhD candidate in the Graduate Program in Dentistry at the Federal University of Sergipe. Her dissertation evaluates the longevity of composite restoration of posterior teeth.

Pollyana Caldeira Leal is post-doctoral fellow in the Graduate Program in Dentistry at the Federal University of Sergipe, Aracaju, Brazil, working mainly with Parkinson's diseases.

Luis Felipe Jochims Schneider is an associate professor in the Department of Restorative Dentistry at Federal Fluminense University, Niteról, Brazil. His research interest includes the development and evaluation of dental materials.

André Luis Faria-e-Silva is an Associate Professor in the Department of Dentistry at Federal University of Sergipe. His research interest includes color evaluation in clinical procedures and dental materials.

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