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The effect of a coupling medium on color and translucency of CAD–CAM ceramics

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ABSTRACT

Objectives: To evaluate color and translucency of ceramics and the influence of a coupling medium (G – glycerin) on these optical properties, testing the hypothesis that glycerin influences the translucency values regardless the evaluation method.
Methods: Five specimens from A2-shaded ceramics (IPS e.max CAD HT and LT, IPS Empress CAD HT and LT, Paradigm C, and Vita Mark II) were fabricated from ceramic blocks and polished to 1.0 ± 0.01 mm in thickness. A spectrophotometer (Vita Easyshade) was used to measure the CIELAB coordinates and the reflectance value (Y) of specimens placed on white and black backgrounds. The translucency parameter (TP) and the contrast ratio (CR) were calculated. Another spectrophotometer (Lambda 20) was used to measure the direct light transmittance (T%) of the specimens. The color and the CIELAB coordinates were evaluated using the Vita Easyshade on neutral grey background and values were used to calculate difference in color (ΔE). All evaluations were repeated using G and values were recorded. Data were statistically analyzed using Anova, Tukey and Student's *t*-test ($\alpha = 0.05$) and Pearson's correlation.
Results: Although the mean translucency values were significantly different for each method (TP and CR), they were strongly correlated ($r^2 = 0.97$), even when G was used ($r^2 = 0.96$).
Conclusion: The coupling medium significantly influenced the mean values of ΔE and translucency.
Clinical significance: Color and translucency values cannot be compared if measured using different coupling media (*e.g.* air and liquid glycerin).

1. Introduction

In recent years, the growing claim for metal-free restorations that match the tooth color increased the demand for aesthetic materials.[1] As the development of CAD/CAM technology continues, the manufacture of all-ceramic restoration is becoming increasingly easy. All-ceramic restorations should match natural tooth structure, color, surface texture, and translucency.[2] Thus, manufacturers are developing ceramic-based materials that are almost indistinguishable from natural teeth,[3] but even so, creating natural-looking aesthetic restorations that blend seamlessly with the surrounding teeth can be difficult.[2]

The study of color and the light interaction with different materials resulting phenomena are subjects that always occupied scientists for their importance and complexity. Many methods to organize and measure color, light reflectance and light transmittance have been presented.[4,5] The CIE (Commission Internationale de l'Eclairage) has been responsible for introducing the main color systems, color difference concepts and illumination patterns used in science to date.[6–8]

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The optical properties of the teeth far transcend color. When light strikes the teeth, part of it is reflected by the tooth surface and the remaining light penetrates the surface and can be reflected, refracted, absorbed by the tooth inner layers or transmitted through the teeth in the oral cavity.[9] Color and lighting effects created in the process are the hallmark of teeth natural appearance. Needless to mention, restorations that only mimic shape and color of natural teeth are easily detected.[10] So, natural look restorations can only be made if an appropriate range of materials are available. Accordingly, ceramic blocks for CAD–CAM technology are no longer monochromatic, offering gradual shades of color and translucency.[11,12]

Color match of aesthetic restorative materials and tooth still remains a challenge in clinical dentistry.[3,7,8] Progress in technology, computers, internet, and communication systems have greatly affected and shaped modern society. Commensurate with these advances are the progress in contemporary dentistry. In recent years, the dental profession has experienced the growth of a new generation of technologies devoted to the analysis, communication and verification of shade.[1,7,8] Despite this technology, the gold standard method for color match still is the comparison of tooth and restoration to color shade guide tabs. Yet, there are electronic methods, such as spectrophotometers, which minimize the subjectivity in shade selection.[3,13,14] Some studies suggested that there is a difference in color perception between the electronic and the visual methods, but this difference is clinically accepted[1,15–17] and both methods should be used to maximize the chromatic effects naturally present in the tooth.[1,14]

Difficulties in maintaining color between material batches and the evaluation of chromatic variations have hindered the use of color shade guides for industrial and scientific applications. Many dentists and laboratory technicians have used the Vita Classical shade guide as a reference to achieve the desired shade of a restoration, regardless the manufacturer of the restorative material. This fact promoted systems that use more specific and universal parameters for determining color, such as the CIELAB.[6,18] Yet, this system is not capable to evaluate opacity and light transmission. These optical phenomena affect color perception and should not be neglected.[3,17]

Differences in the perceived color (ΔE) can be calculated using the CIELAB coordinates. There are different equations to calculate the ΔE, such as the CIEΔE_{76} and CIEΔE2000.[6,19] Data from both equations have showed strong correlation and the limitations of 1976 equation have not been shown to be significant for color differences involving dental materials.[18,20] Yet, research design and statistical analysis may influence the study outcome, especially when correlate to human observations. The CIELAB system has provided quantitative representation of color and it has been extensively applied in dentistry to study aesthetic materials, shade guides, and color reproductions.[18] The ISO/TR standard 28642:1999 defines perceptibility threshold of color difference as the difference in color (DE) that can be detected and the acceptability threshold of color difference as the acceptable color match. It also defines color shifting as the change in perceived color that is a sum of a blending effect and an effect of physical translucency.[21] Yet, there is no consensus in literature about the ΔE threshold value from which the human eye starts to detect a color difference between two materials,[16] meaning, which color difference is noticeable by a viewer and which ΔE is clinically acceptable.[22] However, most studies accept a limit of $\Delta E = 3.0$ to be imperceptible to the human eye.[23] A classic study estimated that the color difference, which indicates acceptance of a restoration and the tooth is $\Delta E = 2.7$,[24] which is an intermediate value from two other studies: $\Delta E = 3.3$[25] and $\Delta E = 2.0$.[26] Additional work using more stringent criteria to ΔE limit, indicate that only values smaller than 1 are completely imperceptible to the human eye, while ΔE values between 1 and 2 are noted by trained observers but they are still clinically acceptable. ΔE values greater than 2 would be perceptible to the untrained eye and, therefore, clinically unacceptable.[27,28] Other clinically relevant studies showed larger range of perceptibility thresholds and color mismatch with ΔE values smaller than 1.9,[29] 3.7,[30] and 2.7[22] for what is clinically imperceptive and ΔE values higher than 4.2,[29] 6.8,[30] and 5.5[22] for what is clinically unacceptable. Therefore, the values between those two thresholds would be considered clinically acceptable for those studies. These reports considered clinical factors such as the influence of lip shadows, tooth shape, tooth position in the dental arch, adjacent teeth, and translucency.

The translucency is the amount of light passing through a material and it is essential to the aesthetic feature of dental restorations. Along with color, translucency is dependent on the material used. There are several methods to evaluate translucency and opacity of aesthetic restorative materials, such as: direct transmittance of light,[4,5] the contrast ratio (CR) and the translucency parameter (TP).[11,31–36] The use of TP to describe translucency of dental materials was first described by Johnston et al. and they used a solution to optically couple the specimen to the backing.[32] Notwithstanding, there is a concern regarding the use of a coupling medium on measuring the optical properties, avoiding the effect of the air refractive index.[12] Despite of these studies, there is no standard or consensus on the method of choice to quantify translucency of aesthetic restorative materials. This is probably due to scientific and technical difficulties related to the methodological development and understanding of different physical phenomena that govern the optical performance and aesthetic of restorative materials.[37] Therefore, the present study was designed to evaluate color and translucency of ceramics and the influence of a coupling medium (glycerin) on these optical properties, testing the hypothesis that glycerin influences the translucency values regardless the evaluation method.

2. Materials and methods

Plate-shaped ceramic specimens (10 mm × 20 mm × 1 mm), shade A2, were fabricated using CAD–CAM technology (Cerec inLab MC XL, Sirona Dental Services GmbH, Bensheim, Germany). All specimens were polished to 1 μm diamond paste and the thickness was measured with a digital calliper (Digimatic calliper, Mitutoyo Corp., Tokyo, Japan). Accepted thickness values were 1 ± 0.01 mm. IPS e.max CAD and IPS Empress CAD present two levels of translucency: HT (high translucency) and LT (low translucency). Therefore both A2

Table 1 – Description of the ceramic materials used in the experimental groups.

Groups[a]	Ceramic brand name	Manufacturer	Ceramic type[b]
EML EMH	IPS e.max CAD	Ivoclar Vivadent, Schaan, Liechtenstein	Lithium disilicate-based glass-ceramic
ECL ECH	IPS Empress CAD	Ivoclar Vivadent, Schaan, Liechtenstein	Leucite-reinforced glass-ceramic
PC	Paradigm™ C Ceramic Block for CEREC	3M-ESPE, Dental Products, St. Paul, MN, USA	Leucite-reinforced glass-ceramic
MII	VITABLOCS Mark II for CEREC inLab	Vita Zahnfabrik, Bad Sackingen, Germany	Feldspathic ceramic

[a] H, high translucency; L, low translucency.
[b] From Della Bona.[12]

shades (A2LT and A2HT) were evaluated. The ceramics of the six experimental groups are described in Table 1.

2.1. Translucency and transmittance evaluation

Translucency can be quantitatively described using a translucency specification such as transmittance, contrast ratio (CR) and translucency parameter (TP), each of which involve optical measurement made at a specified thickness.[38]

An UV/VIS Spectrophotometer (Lamba 20 – Perkin Elmer, Norwalk, CT, USA) was used to measure the direct transmittance of light (in percentage) (*T*%). The calibration parameters of the spectrophotometer in scan mode included: slit of 0.5 nm, scan speed of 240 nm/min, 10 nm smooth, light range of 300–800 nm (visible and ultra-violet) with data interval of 1 nm. The mean *T*% values at 525 nm wavelength were used for comparison between materials and methods.[9]

Another spectrophotometer (Vita Easyshade Advance, Vita Zahnfabrik, Germany) in Tooth Single mode was used to record the CIELAB coordinates from specimens placed on white (W) and black (B) backgrounds. The values were used to calculate the Translucency Parameter (TP) as follows[32,39]:

$$TP = [(L^*_B - L^*_W)^2 + (a^*_B - a^*_W)^2 + (b^*_B - b^*_W)^2]^{1/2} \quad (1)$$

where L^* is the lightness, a^* corresponds to the red–green axis value and b^* to the yellow–blue axis value from the CIELAB color space. The greater the TP value, the higher the translucency of the material.

The L^* values were also used to calculate the spectral reflectance, Y (luminance from Tristimulus Color Space/XYZ) as follows[40]:

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

For simulated object colors, the specified white stimulus normally chosen is one that has the appearance of a perfect reflecting diffuser, normalized by a common factor so that Y_n is equal to 100.[19] Y values of the specimens recorded on white (Y_W) and black (Y_B) backgrounds were used to calculate the Contrast Ratio (CR) as follows[23,31]:

$$CR = \frac{Y_B}{Y_W} \quad (3)$$

CR values range from 0.0 (transparent material) to 1.0 (totally opaque material).

2.2. Color evaluation

The specimens were positioned over a neutral grey background (Munsell N7 – $L^* = 71.6$; $a^* = -0.04$; and $b^* = 0.05$) and a spectrophotometer (Vita Easyshade), in ‘‘Tooth Single’’ mode, determined the values of the CIELAB coordinates and the shade according to the Vitapan Classical. The same parameters were determined using the ‘‘Restoration’’ mode by preselecting A2 shade on the Vita Easyshade menu. In this mode, the device shows the difference between entered shade (default) and the measured shade, as well as the difference between measured coordinate values and standard *Lab* values for the default (selected) shade.

Difference in color perception (ΔE_{76}) based on CIELAB coordinates values was calculated using the equation[26]:

$$\Delta E_{76} = [(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2]^{1/2} \quad (4)$$

Mean ΔE values below 3.0 were considered ‘‘clinically imperceptible’’, ΔE values between 3.0 and 5.0 were considered ‘‘clinically acceptable’’ and ΔE values above 5.0 were considered ‘‘clinically unacceptable’’. These ΔE values were based on average acceptability and perceptibility thresholds from previous studies.[22,24–30]

All color and translucency measurements mentioned above (except *T*%) were repeated using a coupling medium, *i.e.* glycerin (G) between the ceramic specimen and the background board. To identify the values resulted from the use of glycerin as the coupling medium, the letter G was added at the end of the acronym that represents the method.

Color and translucency values measured by different methods were analyzed statistically using analysis of variance and the differences were evaluated by Tukey test ($\alpha = 0.05$). The influence of glycerin was statistically analyzed by Student's *t*-test ($\alpha = 0.05$). The values from the translucency methods were also evaluated by Pearson correlation test to determine the *r*-squared value (coefficient of determination).

3. Results

ECH showed significantly higher direct light transmittance than other ceramics ($p \leq 0.01$). The mean translucency values, measured by TP and CR, of ECH and PC were statistically similar ($p = 0.08$), but greater than the other ceramic groups ($p \leq 0.01$) (Table 2). The use of glycerin as a coupling medium significantly influenced the mean translucency values for both methods (TP and CR) and the color perception ($p < 0.001$, Student's *t*-test) (Table 4, ΔE_G column).

The translucency methods (CR and TP) showed strong correlation ($r^2 = 0.97$) even when glycerin (CRG and TPG) was used as a coupling medium ($r^2 = 0.96$) (Table 3). Yet, the higher correlations of *T*% to each of TP and CR (without G) are probably because of *T*% is obtained without any accounting

Table 2 – Mean and standard deviation values and statistical grouping of ceramics examined for translucency (TP and CR; TPG and CRG, with glycerin) and transmittance (*T*%).

	TP		TPG		CR		CRG		T%	
EML	17.3 ± 0.81	aA	38.0 ± 1.23	aB	0.63 ± 0.02	aC	0.32 ± 0.02	aD	0.26 ± 0.02	a
EMH	19.0 ± 0.16	bcA	42.4 ± 1.01	bB	0.58 ± 0.00	bC	0.23 ± 0.01	bcD	0.33 ± 0.01	b
ECL	19.9 ± 0.73	bdA	41.9 ± 1.46	bB	0.58 ± 0.01	bC	0.26 ± 0.01	bD	0.36 ± 0.02	b
ECH	21.7 ± 0.33	eA	45.7 ± 1.36	cB	0.52 ± 0.00	cC	0.21 ± 0.02	cD	0.47 ± 0.04	c
PC	20.7 ± 0.81	deA	46.5 ± 2.53	cB	0.54 ± 0.02	cC	0.21 ± 0.02	cD	0.35 ± 0.01	b
MII	18.0 ± 0.65	acA	37.6 ± 1.80	aB	0.61 ± 0.02	aC	0.31 ± 0.02	aD	0.28 ± 0.01	a

Different lowercase letters show statistical differences of mean values within same method (column) ($p < 0.01$). Different capital letters show statistical differences in the line between same methods with and without glycerin (TP and TPG columns; CR and CRG columns) ($p < 0.01$).

Table 3 – Pearson correlation matrix (*r*-squared values) for the translucency and transmittance methods.

	TP	CR	T%	TPG	CRG
TP	1.00	0.97	0.87	0.87	0.83
CR	0.97	1.00	0.85	0.90	0.89
T%	0.87	0.85	1.00	0.62	0.65
TPG	0.87	0.90	0.62	1.00	0.96
CRG	0.83	0.89	0.65	0.96	1.00

for interfacial reflection (Table 3), which might account for any discrepancy between these correlations.

Lab coordinate values obtained by the spectrophotometer in "Tooth single" mode on a neutral grey background were used to calculate the mean Δ*E* value between the A2 shades from different ceramics. As expected, the ceramics were not identical but the differences were clinically acceptable (Δ*E* = 3–5) for: EML-ECL, EML-MII, EMH-PC, and ECH-PC. The remaining ceramic combinations were considered clinically unacceptable ($\Delta E > 5$).

As observed for translucency values, the coupling medium (G) significantly influenced the color perception of the ceramics (ΔE_G = 5.6–9.4) (Table 4).

When the *Lab* coordinates values of the ceramic specimens were measured with the Easyshade, using verify "Restoration" mode, which, in this case, considered and compared to the *Lab* coordinates of the standard shade A2, all mean Δ*E* values were clinically unacceptable ($\Delta E > 5$) (Table 5).

4. Discussion

The literature differences on tooth color acceptability and perceptibility using Δ*E* values is probably due to the diversity of observers, objectives and methodologies among the studies.[16,19,24–28] Clinically, the tooth or restoration context and surroundings (*e.g.* skin, lips, gingiva, adjacent teeth, position in the arch, shape, color, translucency, texture, salivary moisture) and the blending effect, tend to expand the clinically acceptable limit previously reported.[12,41] The mean ΔE values used in this study as "clinically imperceptible" ($\Delta E < 3$), "clinically acceptable" (ΔE between 3 and 5) and "clinically unacceptable" ($\Delta E > 5$) seem to be consistent with the clinical practice considering a non-color expert, which usually is the patient's condition. In addition, similar rationale is used by the settings of the spectrophotometer used in this study (Easyshade) in considering poor (*), fair (**), or good (***) shade match in the "Restoration" mode. Yet, similar outcomes were found in previous clinical studies.[22,29,30]

Table 4 – Mean Δ*E* values between ceramics of shade A2. The ΔE_G column shows the mean Δ*E* value of a ceramic evaluated with and without the use of glycerin.

	EML	EMH	ECL	ECH	PC	MII	ΔE_G
EML	–	8.3	3.1	7.0	8.6	4.1	7.7
EMH	8.3	–	10.6	5.8	3.8	6.1	9.4
ECL	3.1	10.6	–	7.5	9.9	7.0	8.4
ECH	7.0	5.8	7.5	–	3.2	7.8	7.3
PC	8.6	3.8	9.9	3.2	–	8.2	5.6
MII	4.1	6.1	7.0	7.8	8.2	–	7.3

The thickness (1 mm), shape (slab) and the monochromatic structure of the ceramic specimens used in the present study differ from tooth and ceramic restoration, but it is the most popular type of specimen used for *in vitro* studies. Yet, it is probably unfair to use this type of specimen for intra-oral color matching exercises. Moreover, the methods used in the present study, except for *T*%, considered the values obtained by a single spectrophotometer (Vita Easyshade) for the *Lab* coordinates and the Classical shades (Vita),[42] supposedly used by other manufactures to name the ceramic shade evaluated. Therefore, the aspects and limitations mentioned above should be taken in consideration to evaluate the results from the present study.

As expected, the ceramics showed different *Lab* values. Yet, all of them were classified by the manufacturers as A2 shade. From the 15 possible ceramic combinations only four were considered clinically acceptable, while the remaining 11 combinations were clinically unacceptable (Table 4). Therefore, the ceramic specimens were unable to express the indicated shade (A2) and also contrast among themselves, agreeing with a classic study.[43] In addition, the same shade A2 can be of high or low translucency (HT and LT) and, therefore, play a significant role in the ΔE value (Table 5).

Although the ΔE value is considered the standard on color measurement, it also has limitations. It only considers the color space (CIELAB coordinates), neglecting other components and factors on color perception, such as: translucency, opalescence, fluorescence, brightness, and surface texture,[11,34,39,44] which are naturally considered by professionals in clinical evaluations, but collectively impossible of being evaluated by instruments.[12,14] The present study should be consider an additional report to show the influence of translucency on color perception.

Table 5 – Mean ΔE values between the standard *Lab* coordinates values of shade A2 (pre-defined on Easy-shade) and *Lab* coordinates values of the ceramic specimens measured by the spectrophotometer Easyshade in "Restoration" mode.

	ΔE
EML	8.3
EMH	11.9
ECL	6.3
ECH	9.6
PC	11.0
MII	10.2

The translucency methods (TP and CR) used in the present study showed a strong correlation, justifying their popularity in the literature.[11,31–34,45–47] Nevertheless, it is an inverse correlation supporting that CR is an opacity parameter. The transmittance (T%) and contrast ratio (CR) may each be totally wavelength-dependent or based on calculations using luminous transmittance or luminous reflectance for contrast ratio. Yet, transmittance is related to material's internal reflection coefficient and it has limitations on materials with a large scattering power such as ceramic.[37] The translucency parameter (TP) was developed to relate human visual perception to the translucency, since TP is defined as the color difference between the reflected colors of the material with a stated thickness backed by black and white backings.[32,38] Furthermore, the translucency values of human enamel (18.7) and dentine (16.4) evaluated by TP[36] under the same conditions as in the present study (without glycerin and 1-mm thick specimens) are clinically relevant to prosthodontics using all-ceramic restorations. Nevertheless, materials with extreme light transmission characteristics, meaning, opaque (*e.g.* polycrystalline zirconia) or transparent (*e.g.* glass) materials cannot be measured by TP and CR.

The refractive index (n) is the ratio between the speed of light in vacuum and the speed of light in a given environment. The n of light in air ($n_{air} = 1.00029$ at 15 °C and 1 atm of pressure) is different from the n of light in humid conditions.[12] To simulate oral environment, color and translucency (except T%) evaluations were also performed using glycerin ($n_G = 1.48$) as coupling medium. Glycerin significantly influenced the translucency (Table 2) and color perception (Table 4, ΔE_G column) values for the examined ceramics, showing the importance of this factor for the evaluation of color and translucency, confirming the study hypothesis.

Although the data presented is unique for the CAD–CAM ceramic materials studied and contributes to the basic understanding of using coupling medium for optical characterization of any translucent aesthetic dental material, there is a need for clinical evaluation of the perceptibility and acceptability thresholds of translucency.

5. Conclusion

The mean translucency values were significantly different for each method (TP and CR), which were strongly correlated even when a liquid coupling medium (glycerin) was used. The glycerin significantly influenced the mean values of ΔE and translucency. The A2 shade from the evaluated ceramics showed different CIELAB values.

Conflict of interest

None declared.

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