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Translucency thresholds for dental materials

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ABSTRACT

Objective. To determine the translucency acceptability and perceptibility thresholds for dental resin composites using CIEDE2000 and CIELAB color difference formulas.
Methods. A 30-observer panel performed perceptibility and acceptability judgments on 50 pairs of resin composites discs (diameter: 10 mm; thickness: 1 mm). Disc pair differences for the Translucency Parameter (ΔTP) were calculated using both color difference formulas (ΔTP_{00} ranged from 0.11 to 7.98, and ΔTP_{ab} ranged from 0.01 to 12.79). A Takagi–Sugeno–Kang (TSK) Fuzzy Approximation was used as fitting procedure. From the resultant fitting curves, the 95% confidence intervals were estimated and the 50:50% translucency perceptibility and acceptability thresholds (TPT and TAT) were calculated. Differences between thresholds were statistically analyzed using Student t tests ($\alpha = 0.05$).
Results. CIEDE2000 50:50% TPT was 0.62 and TAT was 2.62. Corresponding CIELAB values were 1.33 and 4.43, respectively. Translucency perceptibility and acceptability thresholds were significantly different using both color difference formulas ($p = 0.01$ for TPT and $p = 0.005$ for TAT). CIEDE2000 color difference formula provided a better data fit than CIELAB formula.
Significance. The visual translucency difference thresholds determined with CIEDE2000 color difference formula can serve as reference values in the selection of resin composites and evaluation of its clinical performance.

1. Introduction

The increased demand of patients for highly esthetic restorations has driven the development of dental materials with suitable optical properties. Translucency is an important property of dental tissues and materials. Thus, an appropriate determination and communication of optical properties should include translucency, in addition to more popular parameters such as: lightness (L*), a* and b* (CIELAB coordinates), hue angle (h°) and chroma (C*).

Translucency describes the ability of a material to transmit light [1]. The translucency parameter [2] (TP) has been used to assess the translucency of dental materials [3–7]. TP is defined

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as the CIELAB color difference (ΔE^*_{ab}) for a material, at a particular thickness, on optical contact with ideal black and white backings [2]. Aiming to improve correction between perceived and computed color differences of CIELAB formula, the Commission Internationale de l'Éclairage (CIE) [8] recommended the use of CIEDE2000 color difference formula. However, at the moment in the majority of translucency studies in dental literature, the TP is still quantified using the CIELAB color space and its associated color formula (ΔE^*_{ab}).

Thus, determination of TP has shown differences in translucency of different composite resins depending of its shade [9], thickness [10]; matrix composition [11]; filler particle size and content [12,13] and type and amount of the opacifiers used [14].

Perceptibility difference threshold represents the lower perceptual limit, and it is widely applicable, mainly, to develop new color notation systems and their color difference metrics, to study discernible colors by the human visual system [15] and to understand the mechanisms of color vision [16]. However, in many practical situations, differences above the threshold (supra-threshold) are used, passing from perceptibility thresholds or "just noticeable differences" to higher differences, named "acceptable differences" or "tolerances." The industrial interest on these differences is justified, on one hand, by the high cost required to maintain the industrial production below the limits of the visual threshold (perceptible threshold) and, on the other hand, by the need of maintaining the differences under an admissible limit. The complete absence of control (monitoring) should involves a lack of similarity in the production outcome, with negative implications on the overall quality of the product.

In dentistry, there were few attempts [17,18] to reach a translucency perceptibility threshold. A study [17] used the contrast ratio (CR) parameter to evaluate dental porcelains, reporting an overall mean translucency perceptibility threshold of 0.07 and 50% of this population perceived a 0.06 CR (6%) difference in translucency. Another study [18] applied regression equations between TP and CR [19] reporting visual perceptibility thresholds for translucency difference in TP of 2.

Nevertheless, there is no study on the translucency thresholds for restorative dental materials using TP and controlled illumination, recommended viewing geometry and a suitable fitting procedure. Therefore, the purpose of this study is to determine 50:50% acceptability and perceptibility translucency thresholds using the CIEDE2000 (TAT_{00} and TPT_{00}) and CIELAB (TAT_{ab} and TPT_{ab}) color difference formulas and the Takagi–Sugeno–Kang (TSK) fuzzy model, testing the null hypothesis that there is no difference between the acceptability translucency thresholds (TAT_{00} and TAT_{ab}) and between the perceptibility translucency thresholds (TPT_{00} and TPT_{ab}).

2. Materials and methods

2.1. Samples and translucency parameter measurements

Thirty resin composites discs (diameter: 10 mm and thickness: 1 mm) of shade A3 from different commercial brands (Table 1) were fabricated using a 10-mm diameter mold (Smile Line, Switzerland) with adjusted height to 1 mm. The resin composite was inserted into the mold, pressed with a glass slide and light activated (Bluephase Style, Ivoclar-Vivadent, 1100 mW/cm^2) for a total of 40 s (2 × 20 s). Clinically, class III resin-based composite restorations are light activated through a translucent Mylar strip. Therefore, several *in vitro* studies [19–22] use similar procedure, i.e. light activation of resin-based composite specimens through translucent Mylar strip or glass slide to produce a clinically relevant surface finish. It was necessary to overlap two areas of light activation to cover the 10-mm diameter surface of the specimens. All specimens were examined for surface defects under magnification (10×). Specimen thickness was verified using a digital caliper to measure different areas of the specimen.

The spectral reflectance of all 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 mm × 50 mm ceramic tile backgrounds (Ceram, Staffordshire, United Kingdom), using a spectroradiometer (SpectraScan PR-670, Photo Research, Chatsworth CA). Specimens were positioned 30 cm away from the spectroradiometer and measured at 45°. A viewing cabinet (Color Viewing Light 4 BASIC, Just Normlicht) with light source simulating the spectral relative irradiance of CIE D65 standard illuminant was employed to provide consistent viewing conditions. Specimens were placed in the center of the viewing cabinet on a 45° tilted base, which corresponds to diffuse/0° illuminating/measuring geometry (Fig. 1). A saturated sucrose solution (refractive index $n = 1.5$ approximately) was used as coupling media between the specimen and the background [4]. The CIE 1931 2° Standard Colorimetric Observer was used to calculate color coordinates from CIE L*a*b* color system.

Short-term repeated measurements (3/specimen) without replacement were performed on each specimen. Similar to other studies [4,6], a triangular stand was used to support the specimens and avoid specular reflection from the glossy surface.

TP values were determined by calculating the color difference between readings over the black and white background for the same specimen, according to the following CIELAB color difference formula (TP_{ab}) [2].

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

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

In addition, CIEDE2000 (1:1:1) color difference formula was also used to calculate the translucency parameter (TP_{00}):

$$TP_{00} = \left[\left(\frac{L'_B - L'_W}{K_L S_L}\right)^2 + \left(\frac{C'_B - C'_W}{K_C S_C}\right)^2 + \left(\frac{H'_B - H'_W}{K_H S_H}\right)^2 + R_T\left(\frac{C'_B - C'_W}{K_C S_C}\right)\left(\frac{H'_B - H'_W}{K_H S_H}\right)\right]^{1/2} \quad (2)$$

where the subscripts "B" and "W" refer to lightness (L′), chroma (C′) and hue (H′) of the specimens over the black and the white backgrounds, respectively. R_T is the rotation function that accounts for the interaction between chroma and hue

Table 1 – Discs of resin composites and their translucency parameter (TP) values.

Sample	Composite brand	Composite type	Batch number	TP_{ab}	TP_{00}
1	RN	Body	132506A	22.44	13.66
2	RMF	Body	123120U	27.12	16.23
3	RMH	Body	132509C	20.45	12.56
4	FS	Posterior	N544104	23.79	16.72
5	FZ5	Universal	N531743	21.84	14.31
6	FSXTE	Enamel	N462846	25.41	17.56
7	FSXTE	Body	N495017	23.29	15.23
8	FSXTE	Dentin	N526754	16.53	10.06
9	M2	Dentin	F49930	22.14	14.38
10	M2	Dentin	F47198	22.52	14.59
11	SDII	Enamel	130562T	29.32	18.05
12	SDII	Dentin	130210N	24.68	14.99
13	PR	Enamel	07 1114	20.23	13.70
14	ESQ	Universal	5781	23.72	16.48
15	RN	Body	132506A	20.85	12.41
16	RMF	Body	123120U	22.67	13.99
17	RMH	Body	132509C	23.34	14.09
18	FS	Posterior	N544104	23.88	16.55
19	FZ5	Universal	N531743	22.18	14.52
20	FSXTE	Enamel	N462846	24.73	17.00
21	FSXTE	Body	N495017	21.58	14.10
22	FSXTE	Dentin	N526754	17.43	10.46
23	M2	Dentin	F49930	22.67	14.86
24	M2	Dentin	F47198	23.30	15.22
25	SDII	Enamel	130562T	28.02	16.93
26	SDII	Dentin	130210N	21.44	13.09
27	PR	Enamel	07 1114	20.08	13.27
28	ESQ	Universal	5781	23.15	15.83
29	CRX	Universal	0786T	25.06	15.84
30	CRX	Universal	0786T	24.76	15.63

RN; Renamel Nano (CosmedentRestorativeDentistry, Chicago, IL, USA); RMF; Renamel Microfill (Cosmedent Restorative Dentistry, Chicago, IL,USA); RMH; Renamel Microhybrid (Cosmedent Restorative Dentistry, Chicago, IL, USA); FS; FiltekSilorane (3M ESPE, St. Paul, MN,USA); FZ5; Filtek Z500 (3M ESPE, St. Paul, MN,USA); FSXTE; Filtek Supreme XTE (3M ESPE, St. Paul, MN,USA); M2; Miris 2 (Coltène/Whaledent AG, Altstätten, SG, Switzerland); SDII; SDI Ice (SDI Ltd, Bayswater, Victoria; Australia); PR; Premise (Kerr Corporation, Orange, CA, USA); ESQ; Estelite Sigma Quick (Tokuyama Dental Corporaton, Taitou-ku, Tokio, Japan); CRX; Ceram X (Dentsply DeTrey GmbH, Konstanz, BW, Germany).

differences in the blue region. Weighting functions, S_L, S_C, S_H adjust the total color difference for variation in the location of the color difference specimen over the B and W backgrounds in L', a', b' coordinates and the parametric factors, K_L, K_C, K_H, are correction terms for experimental conditions. In the present study, the parametric factors of the CIEDE2000 color difference formula were set to 1.

To calculate using the CIEDE2000 color difference formula, discontinuities due to mean hue computation and hue-difference computation were taken into account, whereby both were pointed out and characterized by Sharma et al. [23].

The 30 disc-shaped specimens were combined to create 50 experimental pairs with TP differences ranging from 0.01 to 12.79 for ΔTP_{ab} and from 0.11 to 7.98 for ΔTP_{00}. Fig. 2 shows the values of ΔTP_{ab} and ΔTP_{00} for the 50 experimental pairs, organized by increasing order of ΔTP_{ab}. The color difference (ΔE) of the experimental pairs were lower than the acceptability color difference thresholds reported by Ghinea et al. [24] ($\Delta E_{00} = 2.23$ and $\Delta E^*_{ab} = 3.48$).

2.2. *Psychophysical experiment*

The 50 experimental pairs were assessed by a panel of 30 observers (20 females and 10 males aged between 22 and 55).

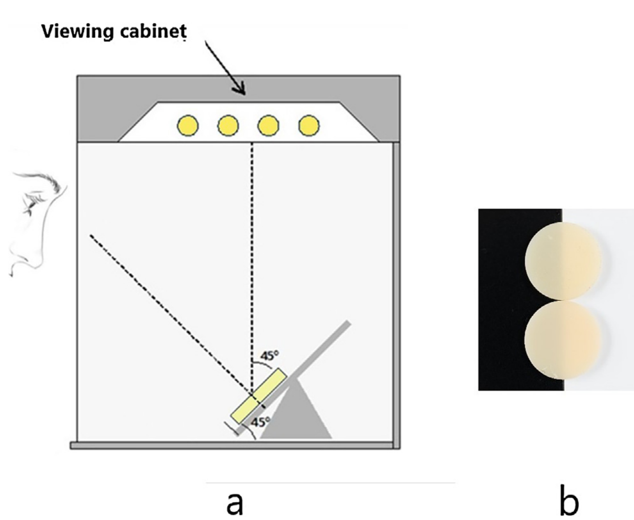

Fig. 1 – (a) Schematic representation of the visual set-up including viewing booth, observation distance of 30 cm, and optical geometry. (b) An experimental pair for visual assessment.

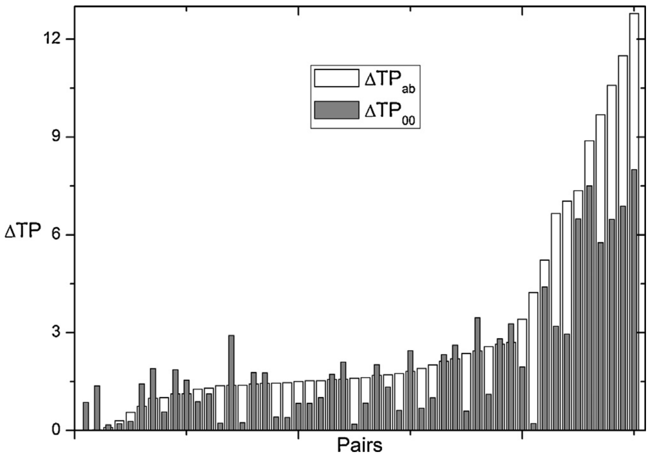

Fig. 2 – ΔTP_{ab} and ΔTP_{00} for the 50 experimental pairs ordered by ΔTP_{ab} values.

The observers were screened for normal color vision using the Ishihara charts (Ishihara Color Vision Test, Kamehara Trading Inc., Tokio, Japan). All observers had previous experience in visual discrimination experiments and moreover were instructed to focus on specimens' translucency.

For the visual assessments, observers were positioned at 30 cm from the experimental pair, which was the same distance used for spectral reflectance measurements. The two ceramic tile backgrounds were used to assist translucency visual judgments (Fig. 1). For perceptibility threshold determination, observers answered the following question: "Can you see a difference in translucency between these two specimens?" Only when the answer was affirmative, observers were asked to answer the following question: "Would you accept the translucency difference between the two resin composite discs under clinical conditions?" Pairs rated as not perceptible were recorded as clinically acceptable translucency difference.

Responses for each pair (yes or no) from each observer were processed and perceptibility and acceptability translucency thresholds were calculated as follows:

$$\%\text{Perceptibility or }\%\text{Acceptability} = S_i/N_t \quad (3)$$

where S_i is the number of observers who answered "yes" and N_t is the total number of observers, which in this case is 30.

2.3. *Fitting procedure*

A Takagi–Sugeno–Kang (TSK) Fuzzy Approximation model [25,26] with Gaussian membership functions and constant consequents was used as fitting method (Matlab 7.1 Fuzzy Logic Toolbox, MathWork Inc., Natick, MA, USA). In the approximations performed, the TSK models took the rule centers equally distributed along the input space, and the rule consequents were optimally obtained using their derivatives with respect to the model output in the minimization of the value of r (Least Squares LSE approach) [27]. The number of rules in each case was selected using a 10-fold cross-validation procedure; the number of rules to which the model provided the lowest cross-validation error was chosen to perform the approximation using all data. The 95% confidence intervals (95%CI), the 95% Lower Confidence Limit (LCL) and the 95% Upper Confidence Limit (UCL) were estimated and the 50:50% (50% of positive answers and 50% negative answers) thresholds were calculated. The 50:50% point was defined as the difference at which an observer would have a 50% probability of making dichotomous judgment and represents the level of acceptability.

Student *t*-tests were used to evaluate the statistical significance in threshold differences ($\alpha = 0.05$).

3. Results

The translucency difference threshold using CIEDE2000 for 50:50% acceptance was $TAT_{00} = 2.62$ (95%CI: 1.01–4.19) with $r^2 = 0.837$ and acceptance threshold using CIELAB formula was $TAT_{ab} = 4.43$ (95%CI: 0–11.05) with $r^2 = 0.490$.

The 50:50% translucency perceptibility thresholds were $TPT_{00} = 0.62$ (95%CI:0–3.02) with $r^2 = 0.680$ using CIEDE2000 and $TPT_{ab} = 1.33$ (95%CI:0–5.05) with $r^2 = 0.371$ using CIELAB color formula.

As an example, Fig. 3 shows the 50:50% translucency acceptability thresholds and the corresponding confidence curves using CIEDE2000 and CIELAB color difference formulas.

The values obtained in this study for TAT_{00} and TPT_{00} correspond, approximately, to 61% and 47% of the TAT_{ab} and TPT_{ab} values, respectively. Also, a significant difference was found between both perceptibility and acceptability translucency thresholds ($p = 0.01$ and $p = 0.005$ for TPT and TAT, respectively).

4. Discussion

TP is based on CIE colorimetry [16] and, therefore, the illumination, the Standard Observer and the color difference formula must also be standardized. Thus, the present study used the CIE 1931 2° Standard Colorimetric Observer, a light source simulating the spectral relative irradiance of CIE D65 standard illuminant and diffuse/0° illuminating/measuring geometry. All these issues were recommended by CIE [8] and has been widely used in previous studies about evaluation of color differences in dentistry [4,6,28,29]. In addition, the thickness of the translucent material significantly affects the color difference [7], thus a micrometer mold was used to fabricate the specimens to a standard thickness that was confirmed right before experimental measurements. Such standardizing procedure may also impose a study limitation, which is the single thickness of specimen (1 mm) used to calculate translucency thresholds.

Color parameters influence on the translucency of resin-based composite [30]. To minimize the influence of color differences on the translucency differences discrimination of experimental pairs, a single composite shade (A3) was selected for all specimens. Such method provided a wide range of translucency differences with a color difference lower than the acceptability color threshold [24].

In addition, as the study variable is the difference in translucency from each experimental pair and the experiment was performed according to ISO/TR 28642:2016 [31], there is a

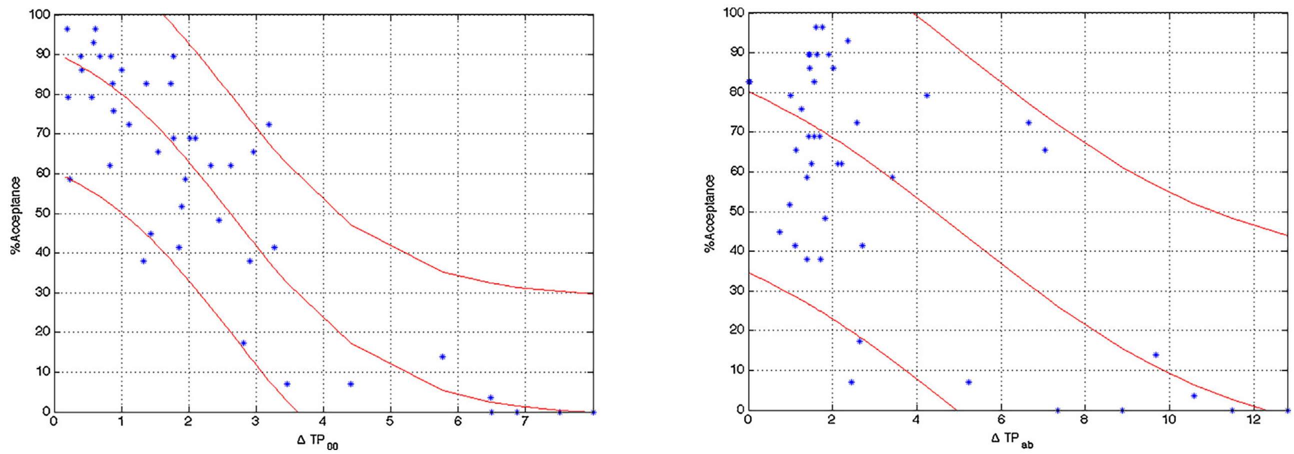

Fig. 3 – Acceptable percentages versus translucency differences (ΔTP00 and ΔTPab) between experimental pairs. Curves denote the 50:50% acceptability translucency threshold (center curve) and its corresponding confidence curves (upper and lower lines) using CIEDE2000 and CIELAB color difference formulas.

great chance the results can be extrapolated to other composite shades and even other esthetic restorative materials. However, further studies are needed to confirm the results of the present study.

The null hypothesis was based on insufficient literature. Experimental results rejected the hypothesis because the acceptability and perceptibility translucency thresholds values were significantly different using both color difference formulas.

The translucency parameter is a direct measure of translucency and it has been used with CIELAB color difference formula. The present study introduced the used of CIEDE2000 formula to calculate TP for a dental material. Results show that CIEDE2000 color difference formula provide a consistently better fit than CIELAB formula in the evaluation of translucency thresholds ($r^2 = 0.837$ versus $r^2 = 0.490$ for TAT and $r^2 = 0.680$ versus $r^2 = 0.371$ for TPT). The use of a suitable translucency parameter is very important to obtain a better correlation of visual judgments to instrumental translucency difference values. Improved correlation provides a more accurate clinical interpretation of translucency differences.

It is well established that the CIEDE2000 formula, which adjusts for the so-called hue-super directions, leads to significant improved performance of the formula to visual data in dentistry [24,29–33], compared to other formulas such as CIELAB and CMC (1:1). Nevertheless, it seems appropriate to continue studying the CIEDE2000 weighting functions (S_L, S_C, and S_H), which may result in even better fit with the visual judgments [33,34]. It is also valuable using efficient research designs to determine the optimum adjustment of functions for translucency of human teeth and dental materials, which would assist on improving the modeling for esthetic materials and, ultimately, patient satisfaction.

A recent review [12] applied regression equations between TP and CR, reporting translucency perceptibility threshold of 2 CIELAB units. Such value was based on data from a study [11] that used feldspathic porcelain with different translucency values. The value of perceptibility translucency threshold using CIELAB formula (TPT_{ab}) obtained in the present study is 1.33, which cannot be compared to the above mentioned study [12] because of differences in methodology and experimental conditions, the mathematical approximation and the adjustment procedures to calculate TPT_{ab}. In addition, CR is not a direct measure of translucency and cannot be used below 50% light transmission [35].

A review on translucency determinations and applications to dental materials have revised and explored the use of translucency parameters [36]. The clinical significance of such literature should be further interpreted in light of perceptibility and acceptability translucency thresholds. Thus, considering reports [6,7] on translucency differences of brands and shades of dental resin composites, Pérez et al. [6] reported that the range of ΔTP values between silorane-based resin composites, universal and nanofilled composites was from 3.5 to 6.3 CIELAB units, which are greater than the perceptibility thresholds obtained in the present study. In addition, translucency differences in shades using CIEDE2000 [7] are larger compared to TAT_{00} and TPT_{00} values of this work. In another study [37], TP determinations were used to show differences between zirconia and human dentin, ranging from 0.8 to 1.3 CIELAB units, which should be no perceptible.

Further, it has been shown a linear correlation between the amount of BisGMA in the resin matrix and transmittance values of composites. Therefore, controlling the amount of BisGMA may be an alternative way to adjust for translucency in esthetic resin-based composites [11]. In this sense, the translucency thresholds determined in the present study can be a reference to learn “a priori” the effect of compositional changes on the visual perceptibility and/or acceptability of this important optical property.

Visual translucency difference thresholds can serve as a quality control tool to guide the selection of esthetic dental materials, evaluate clinical performance, and interpret visual and instrumental findings in clinical dentistry, dental research, and subsequent standardization. The importance of quality control in dentistry is reinforced by increased esthetic demands of patients and dental professionals.

5. Conclusions

Reliable translucency thresholds have been determined. The CIEDE2000 50:50% is $TPT_{00} = 0.62$ units whereas the 50:50% is $TAT_{00} = 2.62$ units corresponding CIELAB values are 1.33 and 4.43 units, respectively.

The CIEDE2000 color difference formula provided a better fit of the data than the CIELAB formula to evaluate translucency difference thresholds of resin composites, which recommends its use for the translucency analysis in dentistry.

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