

ORIGINAL ARTICLE

Measurement of translucency of tooth enamel and dentin

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Abstract

Objective. To determine the translucency of human and bovine enamel and dentin using reflection spectrophotometers. **Material and Methods.** The color of intact human and bovine enamel and dentin specimens was measured over a white and a black plasticine backing using two spectrophotometers with different aperture sizes; translucency parameter (TP) and contrast ratio (CR) were calculated. Plasticine was used as backing because the specimens were not uniform. The TP values of five composite resins measured over the backings of plasticine and reflectance standards were also determined. **Results.** There were no significant differences between the TP values of the composite resins measured over the backings of plasticine and reflectance standards ($p > 0.05$). Mean TP values of 1 mm thick bovine enamel, bovine dentin, human enamel and human dentin were 14.7, 15.2, 18.7, and 16.4, respectively, based on the 3 mm round aperture. There were significant correlations between the TP values measured by the two apertures; the bigger the aperture size, the higher the TP value ($r = 0.87-0.91$, $p < 0.01$). The translucency of enamel and dentin increased in direct proportion to wavelength and in inverse proportion to thickness ($r = 0.87-0.91$). Mean CR values were negatively correlated with the TP values ($r = -0.93$ to -0.78). **Conclusions.** These data could be used as references in the development of esthetic restorative materials and clinical shade-matching.

Key Words: Color, dentin, enamel, plasticine, translucency

Introduction

Translucency is the ability of a layer of colored substance to allow the appearance of an underlying background to show through [1]. It is usually determined by a translucency parameter (TP) or contrast ratio (CR) [1–3]. The TP is the color difference between a uniform thickness of a substance over a white and a black backing, and corresponds directly to common visual assessment of translucency [1]. CR is the ratio of the reflectance of a specimen over a black backing to that over a white backing of a known reflectance, and is an estimate of the opacity of a 1 mm thick specimen [2]. Since the translucency of a substance is a function of wavelength [4], the reduction of a translucency spectrum (wavelength-dependent CR values) to a single parameter (TP) provides a simpler method by which to compare translucency [1].

Optical properties of natural teeth form the basis for clinical shade-matching [5]. Although the

methodology for measurement of the TP has been introduced and several studies on the TP values of dental restorative materials have been reported [1,6–10], there have been no studies identified on measurement of the TP values of tooth enamel and dentin. No values have been proposed for the translucency observable in natural teeth. This lack of previous research may be related to the technical difficulties involved in color measurement of natural teeth. Spectrophotometers and colorimeters are designed to measure flat surfaces [5]; enamel and dentin specimens are usually not flat, however, and they can have surface anomalies, which means a significant edge-loss effect [11,12].

Clay has been used for modeling from the beginning of civilization, and the colors of clay vary from white to black. Plasticine, known as slow drying clay, has become a generic term for modeling clay [13]. Because of the plasticity and varied color of plasticine, it can be used as backing when measuring the

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translucency of irregular-shaped enamel and dentin specimens.

The objectives of this study were: to verify the hypothesis that plasticine can be used as backing in color measurements and to determine the translucency of tooth enamel and dentin using color measuring reflection spectrophotometers.

Material and methods

Preparation of enamel and dentin specimens

Bovine and human enamel and dentin specimens (20 each, i.e. a total of 80 specimens) cut from intact bovine and human teeth were investigated. The teeth were selected at random, provided they were of substantial size and without restorations, fractures, stains, or caries. After storage of the extracted teeth in 0.01% sodium azide (Sigma, St. Louis, Mo., USA) solution, a portion of enamel, including the incisal edge, was separated with a high-speed hand-piece and burs, and was used as an enamel specimen. In addition, a portion of dentin, just beneath the enamel of a tooth, was separated from the enamel and was used as a dentin specimen. Sufficient water was sprayed during the cutting. The specimens were rectangular in shape (bovine 8–14 by 8–10 mm; human 3–6 by 4–9 mm). The cut surface was polished with a diamond point (#145, Shofu, Kyoto, Japan) to the stage that no dentin in an enamel specimen or no enamel in a dentin specimen was observable. The average thickness of each specimen was measured at five different points using a dial gauge (Mitutoyo, Kawasaki, Japan) with point contacts. Specimens were stored in distilled water at room temperature before measurement to reduce the

influence of drying on the measured color [4]. Just before measurement, the specimens were removed from the water and blot dried.

Measurement of translucency of enamel and dentin

Translucency of the bovine specimens was measured using two spectrophotometers with different apertures, i.e. 3 mm round shape and 3 × 8 mm rectangular shape. In the case of the human teeth, only measurement with the 3 mm round aperture was possible because of the small specimen size; however, 14 large-sized human dentin specimens were also measured with the 3 × 8 mm rectangular aperture spectrophotometer.

For the 3 mm round aperture measurement (TP₃), color was measured according to the CIE (Commission Internationale de l'Eclairage) LAB color scale [14] using standard illuminant D65 over white (CIE $L^* = 98.1$, $a^* = -0.5$ and $b^* = 2.8$) and black (CIE $L^* = 4.7$, $a^* = -0.1$ and $b^* = 0.0$) plasticine (Amos, Seoul, Korea: Polyvinyl alcohol) using a reflection spectrophotometer (CM-3500d, Minolta, Osaka, Japan) equipped with an integrating sphere. The illuminating and viewing configuration was CIE diffuse/10° geometry [14]. The ultraviolet (UV) component of the illumination was excluded (UV 0%) and the specular component of reflection was included (SCI geometry). The specimen was first put over the aperture of the spectrophotometer and then a plasticine-filled box was pressed onto it (Figure 1A). Measurements were repeated three times for each specimen.

For measurement with the 3 × 8 mm rectangular aperture (TP₃₈), color was measured using a reflection spectrophotometer (Color-Eye 7000A;

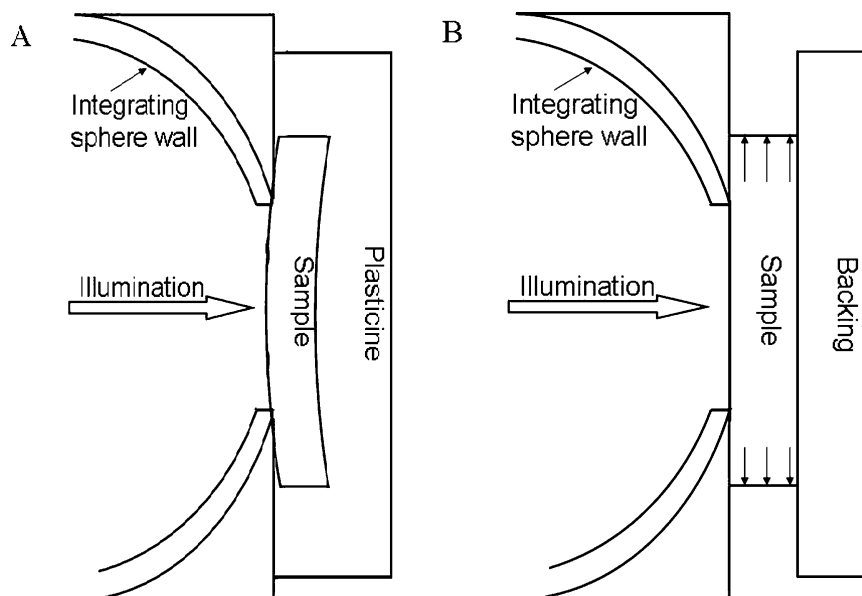


Figure 1. Diagrams of color measurement of a sample over the aperture of an integrating sphere in different configurations. (A) The sample embedded in plasticine. (B) The backing placed conventionally over the sample, the arrows showing possible paths of edge loss.

Gretag Macbeth Instruments Corp., New Windsor, N.Y., USA). Illuminating and viewing configurations complied with CIE diffuse/8° geometry [14]. With the exception of the difference in aperture and configuration of the spectrophotometer, other measurement protocols were the same as the previous ones.

The TP values were obtained by calculating the color difference of the specimen over the white and the black plasticine backings: $TP = [(L_W^* - L_B^*)^2 + (a_W^* - a_B^*)^2 + (b_W^* - b_B^*)^2]^{1/2}$, where subscript *W* refers to the color coordinates over the white backing and subscript *B* to those over the black backing [1]. The CR values were calculated from the spectral reflectance (*Y*) of the specimens with a black (*Y_b*) and white (*Y_w*) backing to give *Y_b*/*Y_w* within the range 400 to 700 nm [2]. Mean CR value was calculated as the averaged CR values at each wavelength (10 nm intervals) in the range 400 to 700 nm.

Measurement of translucency of composite resins with different measurement protocols

Five composite resins (Filtek Z350 Flow, 3M ESPE, St. Paul, Minn., USA; Unifil Flow and Gradia Direct, GC, Tokyo, Japan; Tetric Flow and Tetric Ceram, Ivoclar Vivadent AG, Schaan, Liechtenstein), 10 mm in diameter and 2 mm in thickness (*n*=5), were used as references to determine the influence of plasticine as backing rather than reflectance standards on the TP values. The TP values of the composite resins were measured with three protocols using the two spectrophotometers: (1) TP-1: using white (CIE *L**=95.8, *a**=−0.4 and *b**=2.2) and black (CIE *L**=3.4, *a**=−0.1 and *b**=0.1) reflectance standard ceramic tiles (Minolta, Osaka, Japan) as backings (Figure 1B); (2) TP-2: using smooth plates made of white and black plasticine instead of reflectance standards as backings (Figure 1B); (3) TP-3: using plasticine as backings; the specimens

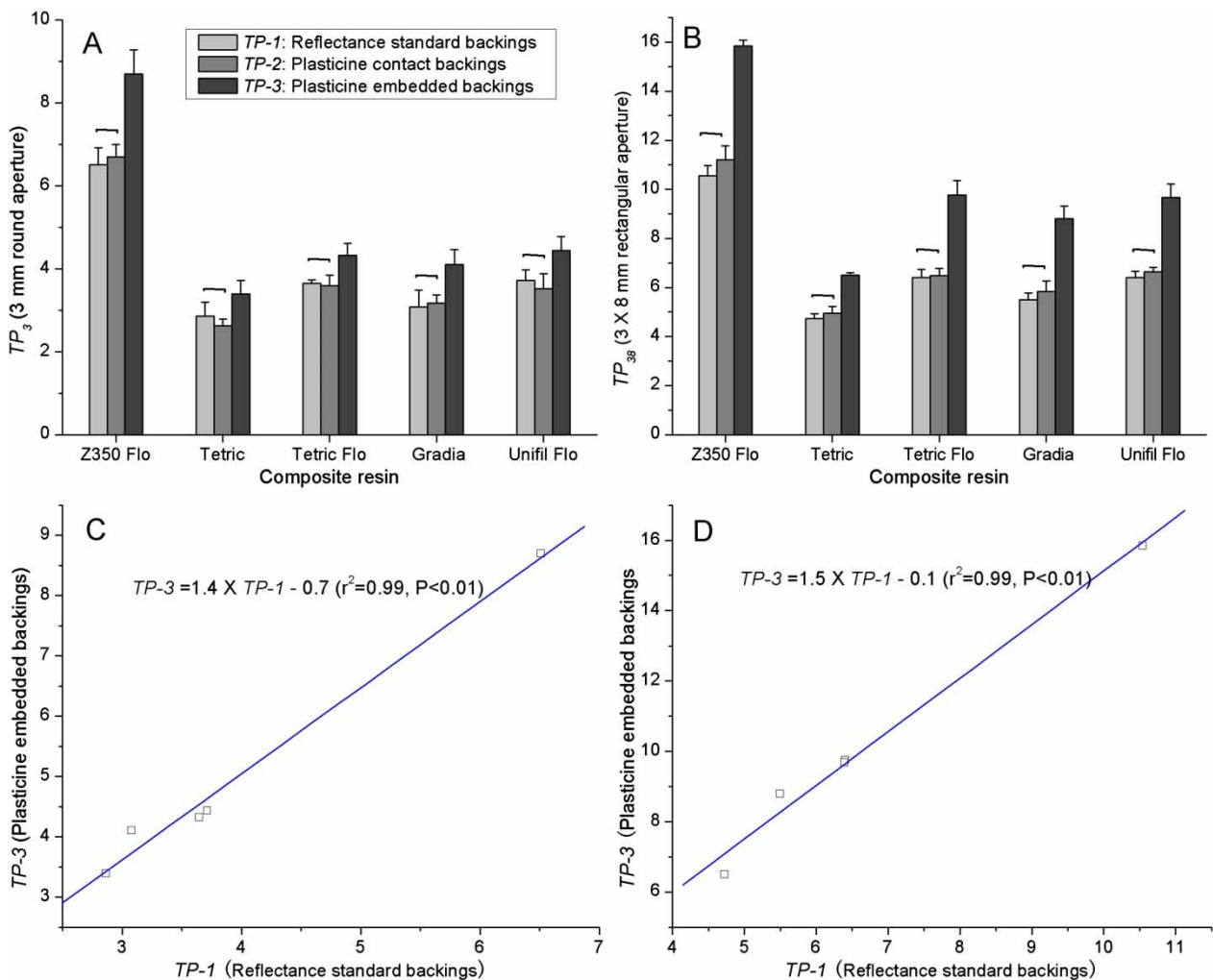


Figure 2. The translucency parameters (TP) of the composite resins measured with different protocols: (A) the 3 mm round aperture and (B) the 3 × 8 mm rectangular aperture. Also the correlations between the TP values measured with different protocols: (C) the 3 mm round aperture and (D) the 3 × 8 mm rectangular aperture. The square brackets indicate no significant difference between the groups at the 0.05 level. There are five specimens in each group.

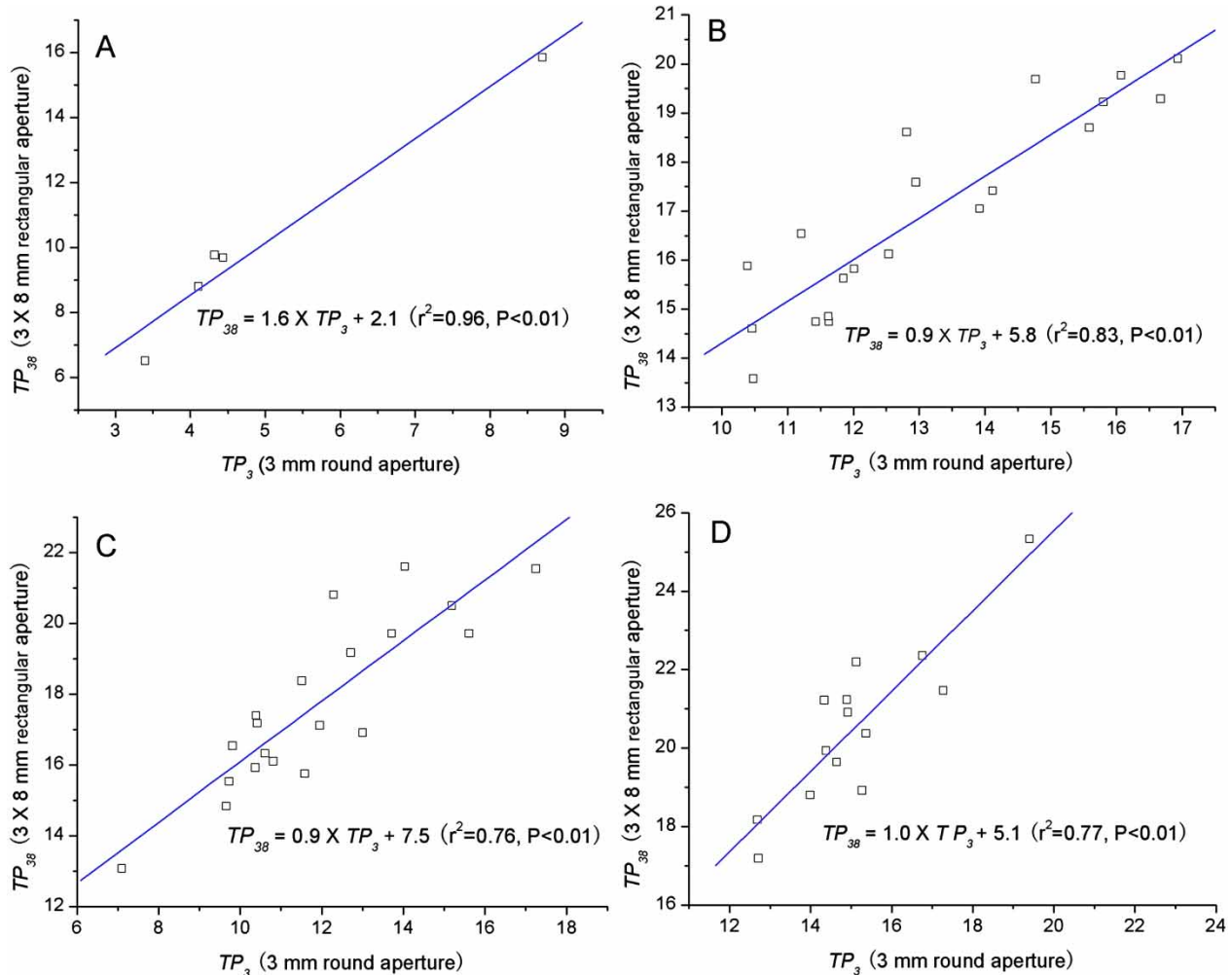


Figure 3. Correlations between the translucency parameters (TP) of (A) composite resins, (B) bovine enamel, (C) bovine dentin, and (D) human dentin measured with the 3 mm round aperture and the 3 × 8 mm rectangular aperture.

were embedded in the plasticine, just like the tooth specimens (Figure 1A). The TP-3 values of 1 mm thick curved specimens that simulated the shape of tooth enamel and dentin specimens, and flat specimens with a composite resin (Filtek Supreme, 3M ESPE) were also measured.

Statistical analysis

To test for a difference in TP values of the resins by backing, one-way ANOVA was performed at the significance level of 0.05 (SPSS v. 12.0; SPSS, Chicago, Ill., USA). A *t*-test was performed to test for a difference in TP values by aperture and specimen shape.

Results

There were no significant differences in the TP values of the composite resins measured with the backings of plasticine or reflectance standards placed conventionally over the specimens, namely TP-1 = TP-2 ($p > 0.05$; Figure 2A and 2B). There were significant correlations between the TP values

measured with the specimens embedded in the plasticine (TP-3) and the TP values measured with the backings placed conventionally over the specimens (TP-1 and TP-2, $r = 0.99, p < 0.01$; Figure 2C and 2D), and TP-3 was significantly higher than TP-1 and TP-2 ($p < 0.01$). No significant difference was found between the TP-3 values of the differently shaped resins ($p > 0.05$).

There were significant correlations between the TP values measured with the two apertures, i.e. the bigger the aperture, the higher the TP values ($r = 0.87\text{--}0.98, p < 0.01$; Figure 3). The thicknesses of bovine enamel, bovine dentin, human enamel, and human dentin specimens were 0.9–1.3, 1.0–2.0, 0.9–1.6, and 0.7–1.6 mm, respectively; the TP values increased in inverse proportion to thickness ($r = 0.80\text{--}0.90, p < 0.01$; Figure 4). Mean TP₃/TP₃₈ values of 1 mm thick bovine enamel, bovine dentin, human enamel, and human dentin were 14.7/18.3, 15.2/21.1, 18.7, and 16.4/21.7, respectively.

Wavelength-dependent CR values of human enamel and dentin measured with the 3 mm round aperture are presented in Figure 5. The CR values of

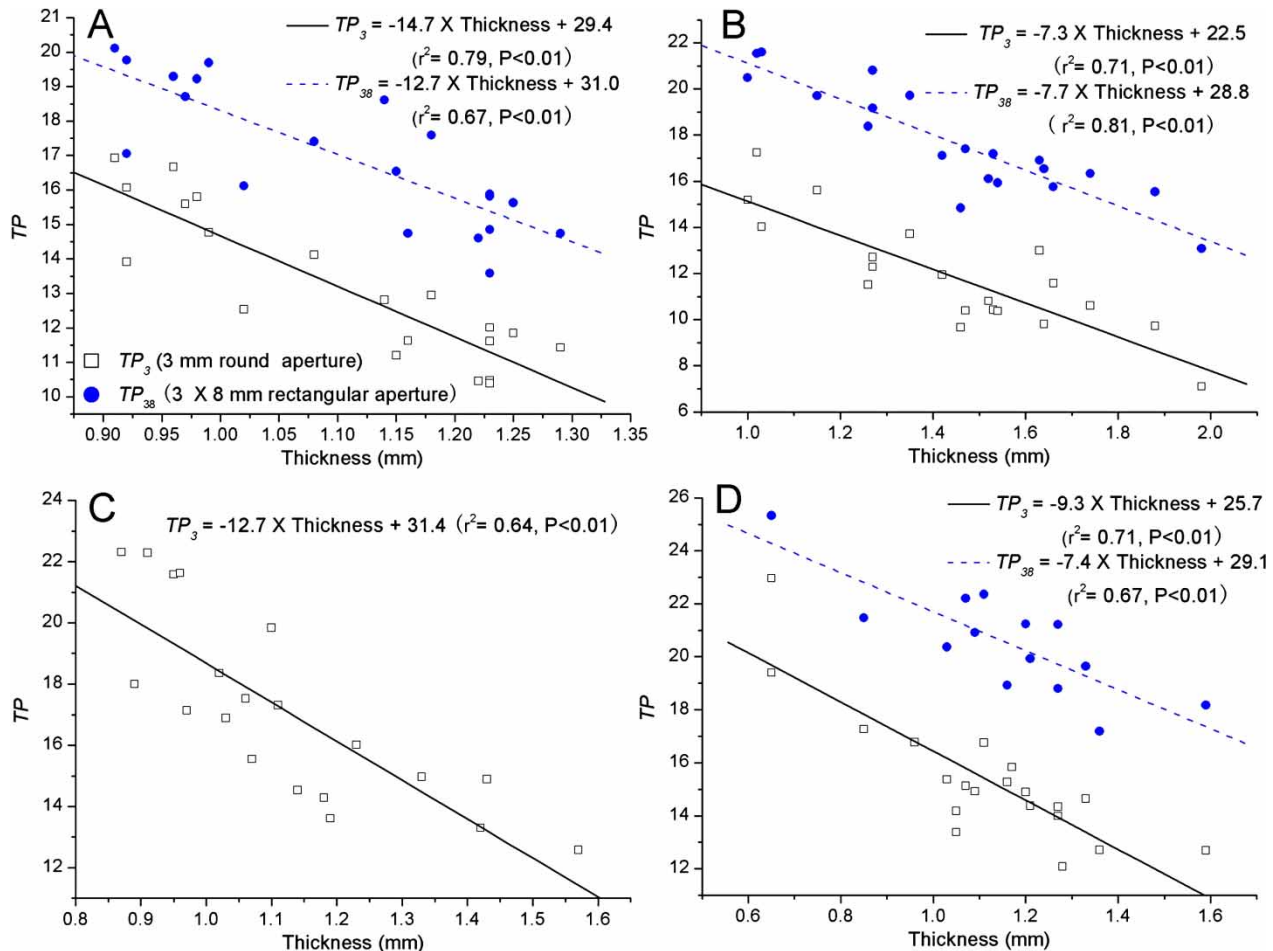


Figure 4. Dependence of the translucency parameters (TP) on thickness of the specimens of: (A) bovine enamel, (B) bovine dentin, (C) human enamel, and (D) human dentin.

enamel and dentin decreased as the wavelength increased.

Correlations between the TP values and the mean CR values of human and bovine enamel and dentin are presented in Figure 6. With all the data based on the average values of each specimen, mean CR was negatively correlated with TP and the correlation coefficient (r) was in the range -0.93 to -0.78 ($p < 0.01$).

The dependences of the TP and CIE L^* , a^* and b^* values of human enamel and dentin measured with the 3 mm round aperture on the thickness of the specimens are presented in Figure 7. Human dentin always showed lower TP values and higher CIE L^* , a^* and b^* values than did human enamel of the same thickness.

Discussion

Edge-loss occurs during reflectance measurements when light is scattered to the edges without being absorbed [11], resulting in loss of accuracy in color measurements [15]. In the present study, we attempted to measure the TP values of tooth enamel and dentin over white and black curved backgrounds

with concave shapes; however, small TP values (< 5) were obtained because the specimens were not directly in contact with the backings. It was assumed the reason for the small TP values was that some of the light was lost at the interface between the specimen and backings without being absorbed; lost light was not therefore detected by the sensor of the spectrophotometer and resulted in the small TP values. To solve this problem of scattering at the interface, plasticine was introduced as a substitute backing in the color measurements.

To determine the influence on TP values of plasticine rather than reflectance standards as backings, translucency of the composite resins was measured over reflectance standards (TP-1) and smooth plasticine plates (TP-2), resulting in no significant difference being found between them ($p > 0.05$). Meanwhile, the CIE L^* , a^* , and b^* values and the spectral reflectance of plasticine were almost the same as the reflectance standards. The color differences (ΔE_{ab}^*) between the white and black plasticine and the corresponding colored reflectance standards were small, i.e. 2.4 and 0.7 ΔE_{ab}^* units, respectively. The hypothesis of the present study was therefore accepted; namely, that

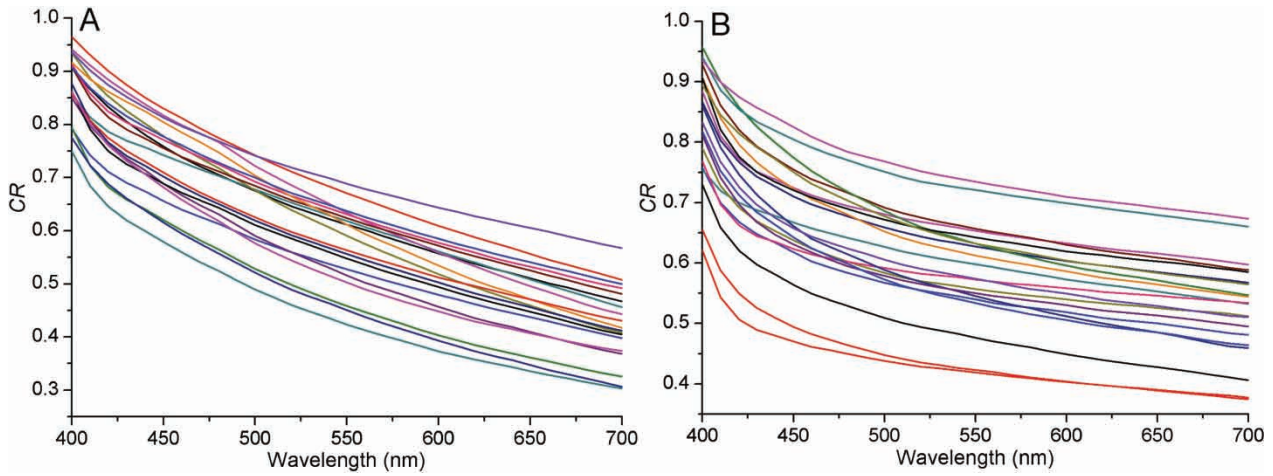


Figure 5. Wavelength-dependent contrast ratios (CR) of (A) human enamel and (B) human dentin measured with the 3 mm round aperture. Different curves represent data from individual enamel or dentin specimens.

plasticine can be used as a substitute backing in color measurements.

In the present study, the edge-loss effect could be minimized when the specimens were embedded in the plasticine because the light reflected to the edges, and reflected back into the specimens, at least partially simulates an ideal situation [12]. The TP

values of the composite resins measured with conventional reflectance measurements (TP-1 and TP-2, which inevitably caused edge losses) were lower than those measured with the specimens embedded in plasticine (TP-3, minimized edge losses), and there were significant correlations between them ($r=0.99$, $p < 0.01$). Furthermore, as there was no

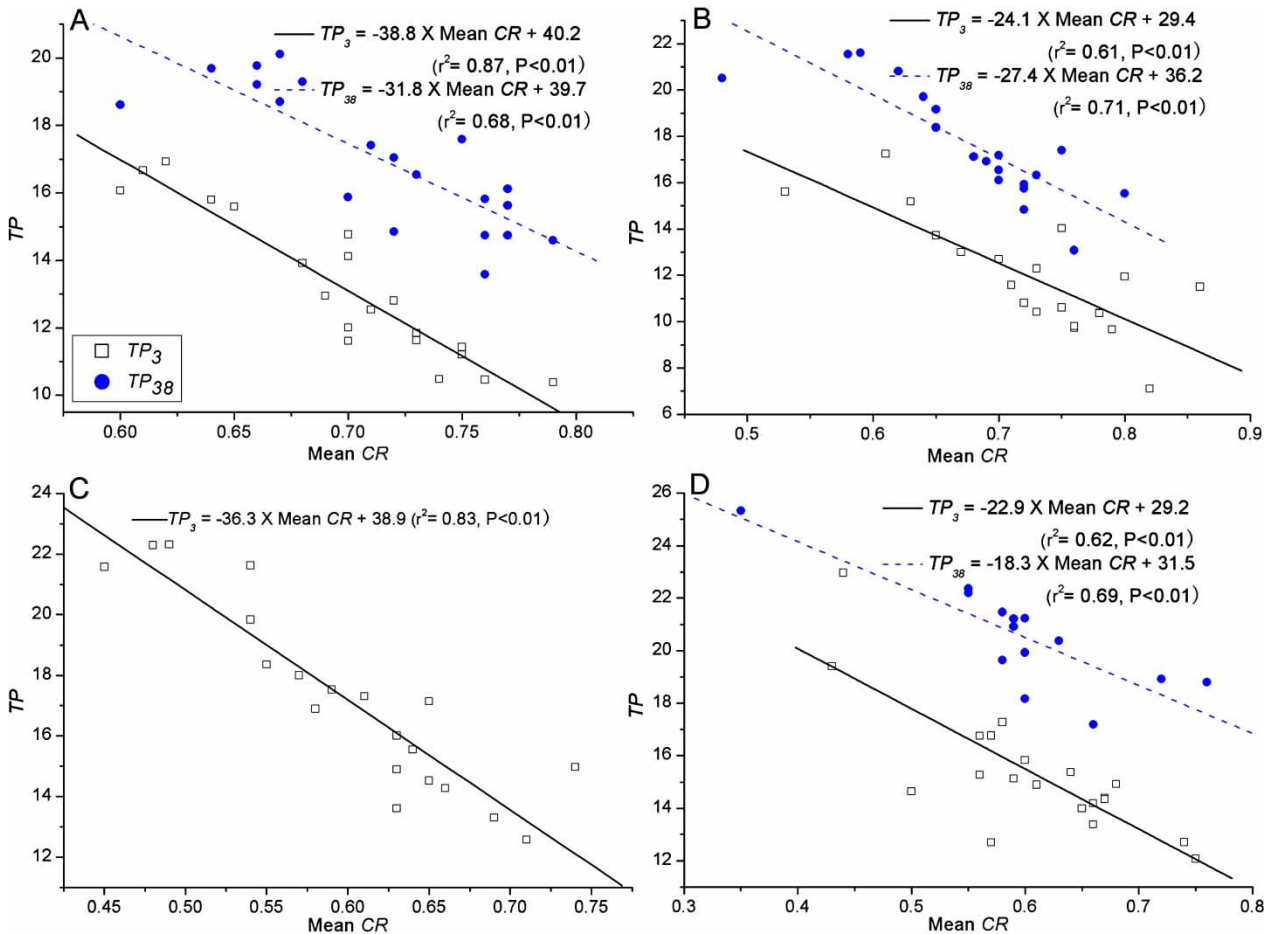


Figure 6. Correlations between the translucency parameters (TP) and the mean contrast ratios (CR) of (A) bovine enamel, (B) bovine dentin, (C) human enamel, and (D) human dentin measured with the 3 mm round aperture and the 3 × 8 mm rectangular aperture.

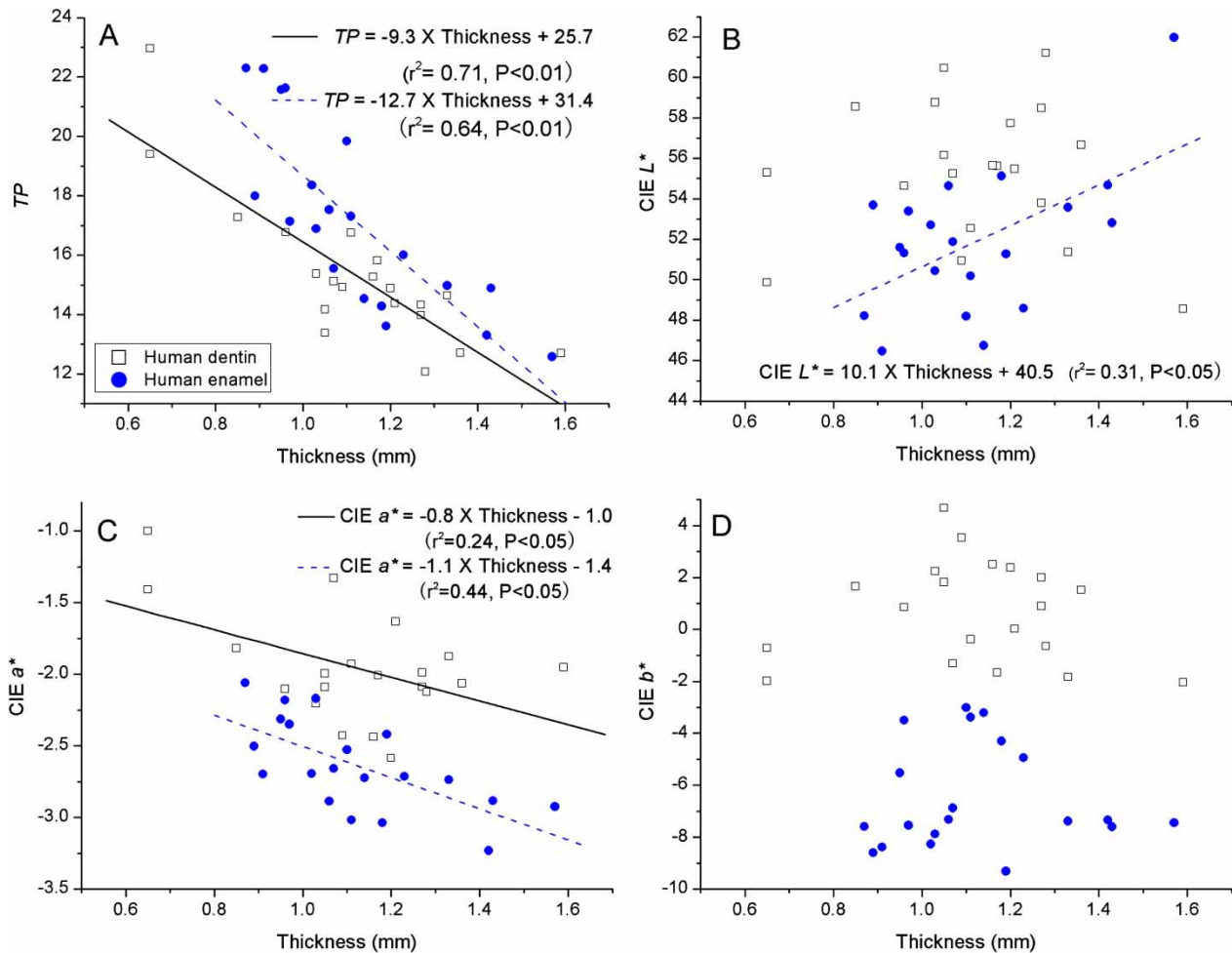


Figure 7. The dependence of (A) the translucency parameters (TP), (B) the CIE L^* , (C) a^* , and (D) b^* values of human enamel and dentin on the thickness of specimens. All the values were measured with the 3 mm round aperture and the CIE L^* , a^* and b^* values over the black plasticine backing.

significant difference in the TP-3 values of the curved and flat resin specimens, the influence of specimen shape on the edge-loss effect was limited in the present study.

Two spectrophotometers with different apertures were used in the present study, and significant correlations were found between the TP values, i.e. the bigger the aperture size, the higher the TP values ($r = 0.87 - 0.91$, $p < 0.01$).

Just like dental restorative materials [8,16], the translucency of tooth enamel and dentin increases in inverse proportion to thickness. The CR values of tooth enamel and dentin at each wavelength show a similar trend to that of dental restorative materials [7,10]; they decrease as wavelength increases, which means translucency increases as wavelength increases. This also confirms a total transmittance study of human enamel [4].

The results of the present study can be used as references in dentistry, and the values in the literature can be re-calculated based on the method described in this study. For example, the range in TP values of 41 composite resins (1 mm thick)

measured with the 3×8 mm rectangular aperture was 8.5–20.6 [10]. Based on the results of Figure 2D: these values were 12.7–30.8 if measured with minimized edge losses (TP_{38}); Figure 3A, 6.3–17.2 if measured with the 3 mm round aperture (TP_3); Figure 4C and 4D, the TP_{38} value for 1 mm thick human dentin is 21.7, while the TP_3 values for 1 mm thick human enamel and dentin are 18.7 and 16.4, respectively. Only a few high translucent composite resins therefore showed similar TP values to those of human enamel and dentin of the same thickness.

Human enamel is prone to be more translucent than dentin, especially when the specimen is thin. Furthermore, under the same thickness condition of the present study, enamel always showed lower CIE L^* , a^* and b^* values than did dentin, which means that, compared to dentin, enamel is darker, reddish and yellowish in color. These results accord with those of studies on enamel-shade and opaque-shade composite resins developed to simulate the optical properties of tooth enamel and dentin in layering techniques [6].

It has been reported that human tooth color is determined mainly by the color of the dentin [17], which confirms the general opinion that the translucency of enamel is greater than that of dentin. In fact, as the result of the present study, the TP value of human enamel is just a little higher than that of dentin of the same thickness. The fact that translucency is a function of thickness in a tooth, and that dentin is thicker than enamel, has generally been ignored. Besides, their differences in the CIE L^* , a^* and b^* values would influence this illusion.

The large deviation in TP values in the present study might partly have been due to differences in the variation in age and sex of the subjects and in the shape (curvature) and surface anomalies of the specimens, since the specimens varied by size of the teeth, and it has been reported that the translucency of human teeth has a tendency to decrease from the incisal site toward the cervical site [18].

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