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RESEARCH AND EDUCATION

Dentin translucency and color evaluation in human incisors, canines, and molars

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ABSTRACT

Statement of problem. For restorations with excellent esthetics, an understanding of the optical properties of human dentin is needed. Little information is available on the translucency and color parameters of dentin and its relationship to tooth type and position.

Purpose. The purpose of this in vitro study was to investigate the translucency and CIELab color coordinates of human dentin in both anterior (incisors and canines) and posterior teeth (molars) by using spectrophotometric and spectroradiometric assessment methods.

Material and methods. Uniformly thick specimens (2 mm) of midcoronal human dentin were taken from 33 central and lateral incisors, 7 canines, and 33 molars (all maxillary teeth). The CIELab color coordinates were measured with a clinical spectrophotometer (Easyshade Compact) and a noncontact spectroradiometer (SpectraScan PR-704). The translucency parameter (TP) was calculated. Bland-Altman plots and Wilcoxon signed rank tests for paired samples were used to assess the agreement of the 2 measurement techniques. The differences between anterior and posterior dentin specimens regarding color coordinates and the translucency parameter were analyzed using Mann-Whitney-Wilcoxon rank sum tests.

Results. Statistically significant differences between spectrophotometric and spectroradiometric measurements of the TP and CIELab color coordinates were found in both groups of dentin specimens ($P<.05$). TP values of molar dentin specimens were significantly higher than those of the anterior ones, regardless of the assessment method ($P<.001$). Dentin specimens of the anterior teeth exhibited higher L* values but lower a* and b* values on both black and white backgrounds compared with molar dentin specimens.

Conclusions. The dentin of anterior teeth was found to be lighter but less translucent and less chromatic than in molars, regardless of the assessment method used. (J Prosthet Dent 2016;115:475-481)

High esthetic demands have necessitated precise reproduction of the optical properties of hard dental structures to be replaced. Consequently, the shade matching of anterior and posterior teeth becomes ever more important. As the conventional method of assessing visual color with shade guides is now considered too subjective,[1,2] prone to error,[3,4] and insufficient with regard to translucency, objective clinical methods are needed to determine and measure the translucency and color of natural teeth and to improve the optical properties of restoration materials.

The performance of spectrophotometers, digital cameras, colorimeters, and spectroradiometers has been investigated over the last 40 years. Spectrophotometers were widely used as the gold standard in several studies[5-8] because of their accuracy, sensitivity, and reproducibility.[9-11] Nevertheless, because they were calibrated with flat opaque standards, systematic measurement errors arose in the measurement of translucent materials, including enamel and dentin.[5,12-14] In addition, in clinical situations, the tip of the instrument cannot make direct contact with the tooth surface, which

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Clinical Implications

Results of the present study provide a database of anterior and posterior dentin translucency and color parameters to improve the clinical optical outcomes of dental composite resins and ceramics.

might be curved, leading to a partial loss of reflected light.[15] This loss occurs because of the sideways displacement of reflected photons, resulting in severe edge losses during color measurements.[14,16] The amount of edge loss depends on the window size and beam size of the spectrophotometer, the thickness and backing of the specimen, and possibly the surface condition of the material.[17] The absorption and scattering properties of specimens were also found to contribute to the edge-loss phenomenon.

Spectroradiometers were introduced into the field of dentistry as an alternative to visual color assessment in order to overcome some of the difficulties found with other objective color measurement methods.[18,19] Spectroradiometers are noncontact instruments with no aperture to restrict external light source and so are not prone to edge-loss effects. As a result, they have been used to determine the color of shade guide tabs,[20] ceramic materials,[21,22] dental structures,[22-25] and enamel and dentin translucency.[22]

A proper chromatic characterization of a dental structure implies measurements of both color and translucency. The color of a specimen in the CIE L*a*b* (CIELab) color space[26,27] refers to 3 different color coordinates: L* refers to lightness, a* is red-green axis, and b* is blue-yellow axis.[26,28] Translucency of a material directly involves 3 parameters: the contrast ratio, transmittance, and translucency parameter (TP). The translucency parameter is defined as the Euclidean color difference between CIELab color coordinates of a material with a precise given thickness measured against a black and a white background.[29] Several studies have used the TP to show differences between human and bovine enamel or dentin,[22,23] translucent composite resins and natural enamel,[30] direct or indirect composite resins,[31-33] dental ceramic materials,[21,34-36] and maxillofacial elastomers.[29]

Although human dentin structure is known to vary from one type of tooth to another,[37] no studies have investigated the comparative color and translucency of anterior and posterior human dentin. This may be because of the difficulty in obtaining a large number of extracted human teeth which are free of caries, pathological discolorations, or any conservative or prosthetic restorations.

The purpose of the present study was to compare the TP and CIELab values measured with a clinical spectrophotometer to those measured with a noncontact spectroradiometer and to evaluate the translucency and color coordinates of both anterior (incisors and canines) and posterior (molars) human dentin. The null hypotheses tested were that the TP and CIELab values measured with the spectroradiometer would not differ from those measured with the spectrophotometer and that the color coordinates and translucency parameter of anterior human dentin would not differ from the corresponding values of posterior human dentin.

MATERIAL AND METHODS

This study was approved by the Ethical Board of the local University (no. 406). A total of 81 human maxillary teeth extracted for therapeutical reasons (33 central and lateral incisors, 7 canines, and 41 molars) were used in this study. All selected teeth were of above average sizes and free of conservative or prosthetic restorations, caries, or pathological discoloration. After extraction, all teeth were cleaned with brushes under a water jet and stored in distilled water at room temperature until their preparation. Each tooth was embedded in transparent acrylic resin (Premacryl Plus; Spofa Dental), forming cylinders 3.5 cm high and 3 cm in diameter. To obtain the largest possible dentin slices, molars were embedded with their occlusal surface toward the base of the cylinder, whereas anterior teeth (incisors and canines) were embedded with their labial surfaces toward the base. All cylinders were fixed to a custom-built metal support adapted to a precision sectioning saw (Isomet 1000; Buehler). The occlusal enamel for molars and the labial enamel for incisors and canines was removed by sectioning with a diamond disk at low speed (250 rev/min) under constant water cooling, till midcoronal dentin was exposed. Then, dentin slices (2.1 mm thick and 10 mm in diameter) embedded in acrylic resin were made by horizontal sectioning.

All 81 slices were manually polished under constant pressure with wet silicon carbide sheets (Klingspor Schleifsysteme; GmbH & Co. KG) of 400, 600, 800, 1000, 1500, and 2000 grit. The same operator (I.S.P.) produced uniformly thick specimens (2 mm, as measured with an electronic digital caliper; Powerfix Profi+; OWIM GmbH & Co. KG) of midcoronal dentin with a circumferential ring of enamel embedded in the center of a transparent acrylic resin block.

All specimens were stored in distilled water at room temperature for 24 hours for rehydration and were removed from the water and dried just before the spectrophotometric measurements were made. CIELab color coordinates of dentin specimens against black (L*=2, a*=1.1; b*= −1.1) and white (L*=93.3; a*= −1.1, b*=1.9) ceramic backgrounds were measured with a clinical spectrophotometer (Easyshade Compact; Vita Zahnfabrik)

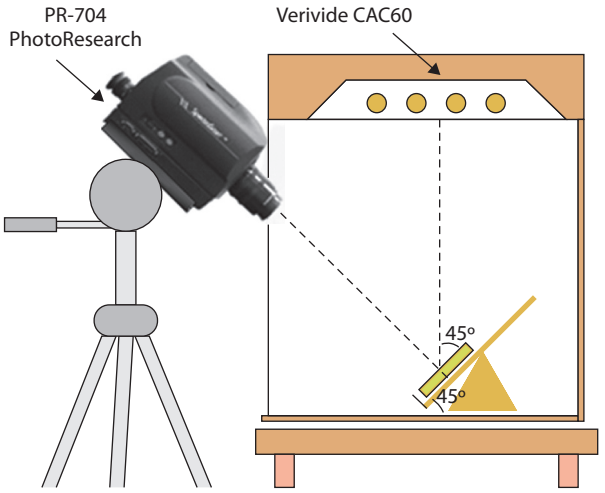

Figure 1. Schematic setup of illumination and measurement geometry used for spectroradiometric measurements of dentin specimens.

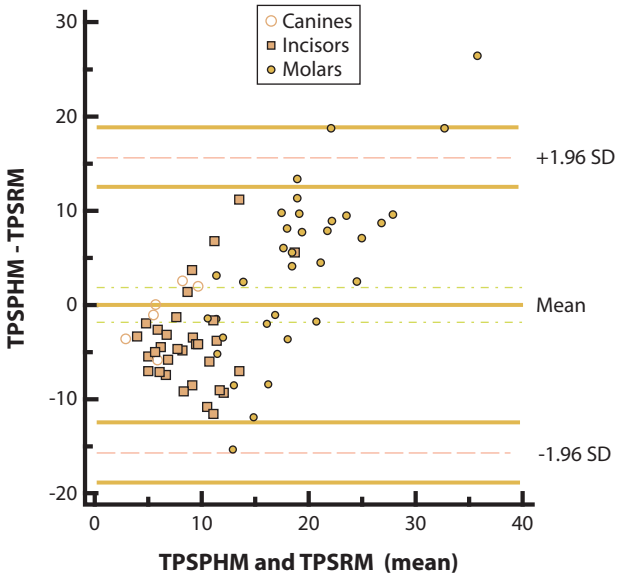

Figure 2. Bland-Altman plot showing comparison between translucency measured using spectrophotometry (TPSPHM) and translucency measured using spectroradiometry (TPSRM) in 33 incisors, 33 molars, and 7 canines.

with a sucrose solution (n=1.5) interposed. Specimens were placed in the center of a viewing booth (JUST LED Color Viewing Light; JUST Normlicht) and illuminated with a light source simulating the CIELab D65 standard illuminant. The probe tip of the instrument was placed perpendicularly to and in contact with the flat surface of the central area of the molar specimens and the middle third of the labial surface for anterior teeth. Measurements were repeated 3 times, and results were averaged. The spectrophotometer was calibrated before each measurement and used according to the manufacturer's instructions.

A noncontact spectroradiometer (SpectraScan PR-704; Photo Research) was used to measure the reflectance spectra of all dentin specimens against black (L*=2; a*=1.1, b*= −1.1) and white (L*=93.3, a*= −1.1, b*=1.9) backgrounds. Specimens were placed 40 cm from the spectroradiometer on a base tilted 45 degrees in the center of a VeriVide CAC60 viewing cabinet (VeriVide Ltd.) and illuminated with a light source simulating the CIE D65 standard illuminant (illuminating/measuring geometry diffuse/0 degrees) (Fig. 1). CIELab values were calculated according to the CIE 1931 2 degrees Colorimetric Standard Observer and the CIE D65 standard illuminant. Results for each specimen and background were averaged over the 3 measurements.

TP values for both the spectrophotometric and spectroradiometric measurements were calculated according to the following formula[29]:

$$TP=\sqrt{(L^*_B-L^*_W)^2+(a^*_B-a^*_W)^2+(b^*_B-b^*_W)^2},$$

where subscript *W* refers to the color coordinates of a specimen over the white background and subscript B to the color coordinates of the specimen over the black background.

CIELab values of 8 molar specimens over the white background could not be recorded with the spectrophotometer because "error" mode appeared repeatedly on the instrument screen. Thus, only 33 molars, 33 incisors, and 7 canines were included in the statistical analysis.

After an initial investigation using Q-Q plots and Kolmogorov-Smirnov tests, the normality of data distributions could not be guaranteed for most of the variables studied. Therefore, the Wilcoxon signed rank test was used to compare paired measurements and the Mann-Whitney-Wilcoxon rank sum tests were used to compare independent samples. The level of significance for hypothesis testing was set at α=.05. The agreement of the 2 measurement techniques was further investigated by using Bland-Altman plots. All statistical analyses were made with software (Excel 2010, Medcalc v13.2.2 and R 3.0.2, environment for statistical computing and graphics; Microsoft Corp).

RESULTS

Bland-Altman plots charting differences between the TP values measured by spectrophotometry (SPHM) and spectroradiometry (SRM) relative to the mean TP measurements of the 2 methods for all 73 teeth is presented in Figure 2. For incisors and canines, differences between measurements of the 2 devices were smaller, centered around 0, compared with the differences for molars.

Means, medians, and standard deviations for all color coordinates and TP values registered with both measurement methods are presented for all teeth in Table 1, for incisors and canines only in Table 2, and for molars

Table 1. TP and CIELab color coordinates of dentin specimens from all teeth measured using SPHM and SRM

	SPHM				SRM			
Parameter	**Mean**	**Median**	**Standard Deviation**	**Count**	**Mean**	**Median**	**Standard Deviation**	**Count**
TP	13.47	9.85	10.29	73	13.46	13.24	5.04	73
CIE L^*_b	69.75	71.17	13.59	73	74.32	75.34	6.69	73
CIE L^*_w	77.38	79.60	12.01	73	82.91	83.21	4.96	73
CIE a^*_b	1.67	0.80	4.06	73	-0.81	-0.95	1.40	73
CIE a^*_w	5.63	3.87	5.23	73	2.39	1.93	2.84	73
CIE b^*_b	36.49	36.40	8.88	73	20.83	20.20	4.67	73
CIE b^*_w	45.46	49.10	10.56	73	30.48	31.27	6.84	73

a^*_b, red-green axis over a black background; a^*_w, red-green axis over a white background; b^*_b, blue-yellow axis over a black background; b^*_w, blue-yellow axis over a white background; CIE, Commission Internationale de l'Eclairage; L^*_b, lightness over a black background; L^*_w, lightness over a white background; SPHM, spectrophotometer; SRM, spectroradiometer; TP, translucency parameter.

Table 2. TP and CIELab color coordinates of dentin specimens from incisors and canines measured using SPHM and SRM

	SPHM				SRM			
Parameter	**Mean**	**Median**	**Standard Deviation**	**Count**	**Mean**	**Median**	**Standard Deviation**	**Count**
TP	6.85	5.55	4.37	40	10.35	9.70	3.50	40
CIE L^*_b	77.12	78.20	11.03	40	78.14	78.91	4.32	40
CIE L^*_w	80.31	83.98	12.07	40	84.99	84.90	3.47	40
CIE a^*_b	1.38	0.30	4.40	40	-0.85	-1.11	1.25	40
CIE a^*_w	3.55	1.63	4.89	40	1.46	1.36	1.78	40
CIE b^*_b	33.58	34.75	8.64	40	18.74	18.49	3.73	40
CIE b^*_w	38.13	37.93	8.40	40	25.93	25.10	4.65	40

a^*_b, red-green axis over black background; a^*_w, red-green axis over white background; b^*_b, blue-yellow axis over black background; b^*_w, blue-yellow axis over white background; CIE, Commission Internationale de l'Eclairage; L^*_b, lightness over black background; L^*_w, lightness over white background; SPHM, spectrophotometer; SRM, spectroradiometer; TP, translucency parameter.

Table 3. TP, CIELab color coordinates of dentin specimens from molars measured using SPHM and SRM

	SPHM				SRM			
Parameter	**Mean**	**Median**	**Standard Deviation**	**Count**	**Mean**	**Median**	**Standard Deviation**	**Count**
TP	21.49	22.09	9.69	33	17.22	17.32	3.95	33
CIE L^*_b	60.81	62.80	10.82	33	69.70	68.53	6.14	33
CIE L^*_w	73.84	74.03	11.11	33	80.38	81.40	5.35	33
CIE a^*_b	2.03	1.33	3.65	33	-0.75	-0.70	1.58	33
CIE a^*_w	8.15	8.27	4.51	33	3.52	3.82	3.44	33
CIE b^*_b	40.03	39.67	7.93	33	23.36	23.18	4.47	33
CIE b^*_w	54.35	54.90	4.03	33	36.00	35.91	4.65	33

a^*_b, red-green axis over black background; a^*_w, red-green axis over white background; b^*_b, blue-yellow axis over black background; b^*_w, blue-yellow axis over white background; CIE, Commission Internationale de l'Eclairage; L^*_b, lightness over black background; L^*_w, lightness over white background; SPHM, spectrophotometer; SRM, spectroradiometer; TP, translucency parameter.

only in Table 3. When TP values for all teeth were compared, no significant differences were found between the medians of the 2 devices (P=.698). However, compared by groups of teeth, the Wilcoxon signed rank test identified significant differences between the median TP values measured by the 2 devices for incisors and canines (P<.001) (Fig. 3) and for molars (P<.05) (Fig. 4). For incisors and canines, the median TP value given by SRM was higher (P<.05) than that of the SPHM value. However, for molars, the SRM TP median value was lower than that of the SPHM TP median value.

Statistically significant median differences were also identified when the Wilcoxon signed rank test was used to compare the mean values of the L^*_b, L^*_w, a^*_b, a^*_w and b^*_b, and b^*_w colorimetric coordinates measured by the 2 devices in all 73 dentin specimens (P<.001).

SPHM measurements showed no statistically significant differences for the median values of L^*_b and L^*_w coordinates (P=.847 and P=.051, respectively) for incisors and canines compared with SRM measurements. Nevertheless, significant differences (P<.001) for the median values of the a^*_b, a^*_w, b^*_b, and b^*_w color parameters were found between the 2 assessment methods.

For molars, significant differences (P<.001) were found between the 2 measurement devices for all studied colorimetric parameters. For both groups of teeth, SRM showed higher lightness values than those of SPHM, whereas SRM a* and b* median values were consistently lower than those given by SPHM.

Median values and the significance of their correspondence for CIELab color coordinates and for the TP of anterior and posterior teeth dentin specimens measured

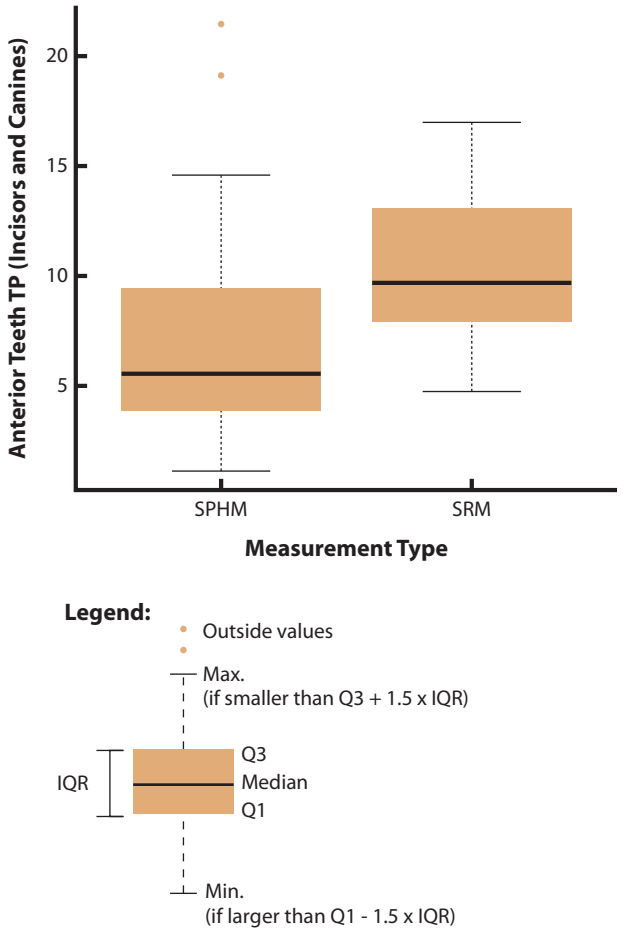

Figure 3. Median and quartile distribution of translucency (TP) measured using spectrophotometry (SPHM) and measured using spectroradiometry (SRM) in dentin specimens from 33 incisors and 7 canines.

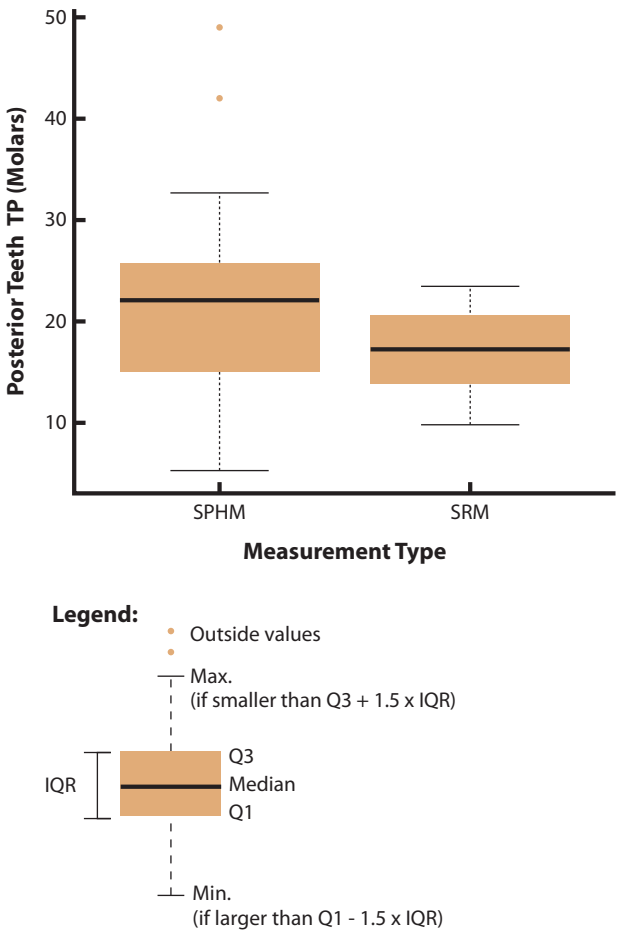

Figure 4. Median and quartile distribution of translucency (TP) measured using spectrophotometry (SPHM) and using spectroradiometry (SRM) in dentin specimens from 33 molars.

using both spectrophotometry and spectroradiometry are presented in Table 4. The Mann-Whitney-Wilcoxon rank sum test revealed significant differences among the TP values of anterior and posterior teeth, regardless of the color-assessment method used ($P<.001$). Significant differences ($P<.001$) were also found between the 2 groups of teeth with both devices for the L* and b* color parameters, irrespective of the background used for color measurements.

Statistically significant differences were also found between the anterior and posterior dentin specimens for the a^*_w color coordinate median values, while no statistically significant differences were found for the a^*_b color-coordinate median values for the 2 groups of teeth ($P=.130$ for SPHM and $P=.608$ for SRM), regardless of the measuring device.

DISCUSSION

The first null hypothesis of this study was rejected. Even though in an overall comparison of all dentin specimens no statistically significant differences in the TP were found between the 2 devices, compared by groups of teeth, the SRM registered significantly higher TP values for anterior teeth and significantly lower TP values for molars than those found by SPHM. The lack of statistical differences between the TP values measured by the 2 devices, in the case of the overall comparison of all the dentin specimens, was due to the above-mentioned opposing differences in the TP between the 2 groups of teeth (anterior and posterior), as confirmed by the Bland-Altman plot presented in Figure 2.

A previous study reported that the SRM-based TP values of the core, veneer, and layered ceramic disks were higher than those measured with a reflection spectrophotometer.[19] The authors ascribed those results to the spectroradiometer's larger illuminating area, which led to higher amounts of reflected light being captured by the SRM detector over the white background.[19] In the present study, this phenomenon could explain the higher TP values given by SRM for anterior dentin specimens. However, the translucency of a material is strongly related to its scattering, transmittance, and absorption

Table 4. TP and CIELab color coordinates of dentin specimens from anterior teeth (33 incisors and 7 canines) and molars (33) measured using spectrophotometry and spectroradiometry

	SPHM[a]			SRM[a]		
Parameter	Incisors and Canines	Molars	*P*	Incisors and Canines	Molars	*P*
TP	5.546	22.093	<.001	9.698	17.321	<.001
CIE L^*_b	78.200	62.800	<.001	78.912	68.528	<.001
CIE L^*_w	83.983	74.033	<.01	84.899	81.397	<.001
CIE a^*_b	.300	1.333	.130	-1.109	-0.702	.608
CIE a^*_w	1.633	8.266	<.001	1.359	3.819	<.01
CIE b^*_b	34.750	39.666	<.01	18.488	23.178	<.001
CIE b^*_w	37.933	54.900	<.001	25.098	35.907	<.001

a^*_b, red-green axis over black background; a^*_w, red-green axis over white background; b^*_b, blue-yellow axis over black background; b^*_w, blue-yellow axis over white background; CIE, Commission Internationale de l'Eclairage; L^*_b, lightness over black background; L^*_w, lightness over white background; SPHM, spectrophotometer; SRM, spectroradiometer; TP, translucency parameter.
[a]Values are median.

and therefore further research on the optical properties of anterior and posterior human dentin is needed to fully understand and explain the behavior of light when passing through this material.

Edge loss was another factor that amplified the discrepancies between the 2 devices. Several studies have shown that edge loss appears when translucent materials such as dental structures are measured.[5,14] SRM measurements were not subjected to edge loss, because the entire surface of each specimen was uniformly illuminated and the measuring spot was considerably smaller than the central area of the specimen. Moreover, the SRM has no diaphragm to restrict the illumination; its illuminated area is, therefore, larger than that of the clinical SPHM[19] used in this study, which has its own illuminating source and is provided with circumferential illuminating optics.[13] The tip of this instrument is used both to illuminate and to collect reflected light and therefore has a larger diameter than the measuring spot. Consequently, because of sideways displacement, the volume of reflected light measured is reduced, resulting in inaccurate readings of color coordinates.

Ambient light affects colorimetric measurements.[15] When color is measured with devices that include their own light source, as in the case of SPHM, the ideal measuring conditions include the complete lack of ambient illumination; however, this ideal arrangement is almost impossible to achieve in clinical situations. In the present study, in order to mimic a clinical situation, but in the meantime provide consistency to the measurements, a standardized consistent illumination was used for SPHM measurements. However, for specimens where the optical coupling between the specimen and the measuring tip of the device was not perfect, this ambient light might have interfered with the SPHM calibration system, causing the device to display an "error" message for 8 molar dentin specimens. These findings confirm the hypothesis that TP and CIELab values, measured by SRM and SPHM, are influenced by the illuminating configuration of the device and by the intensity of the ambient illumination.[5,19,21] Consistent with other measurements on natural teeth,[16] in the present study, SRM showed higher lightness values and lower a* and b* values compared with SPHM measurements. These discrepancies may be attributed either to the high translucency of anterior and posterior teeth dentin specimens or to the small window size of the SPHM and to the different measuring conditions, both of which can influence the degree of edge loss.[17]

The second null hypothesis tested was also rejected. The incisor and canine dentin specimens showed lower translucency values than did the molar dentin specimens, regardless of the assessment method. One possible explanation for these discrepancies is the different light propagation at the dentin level for the 2 groups of dentin specimens. All incisor and canine dentinal tubules were cut obliquely, whereas molars were subject to a transverse section in their midcoronal portion, which resulted in cross-cut dentin tubules constituting the middle of the specimen. The tubule section seems to play an important role in light propagation inside human dentin.[38,39] Light is guided along the tubular spaces that may contain water, air, mineral deposits, or dentinal fluid, with different refractive indices, thereby affecting the transmittance, reflectivity, scattering, and light absorption as well as providing a fiber-optic effect.[40] Challenging this theory, Kienle et al[41] demonstrated that the collagen fibers were key to the scattering phenomenon within dentin. Without the contribution of collagen fibers, no light would be emitted from the dentin specimens. Several studies have reported that besides the number and the diameter of dentin tubules, the type of teeth,[37] subject age or sex, tooth anatomy,[42] and sclerotic alterations[43] could also affect the light characteristics of the dentin.

In the current study, for specimens 2 mm thick, the mean TP value found for the molar dentin specimens (17.22 ±3.95) measured using SRM was consistent with previously reported values for human dentin.[22,23] Pecho et al[22] established a value of 17.2 ±1.8 for the mean TP value of 0.5-mm–thick slices of medial superficial human dentin from 5 human anterior maxillary teeth. Yu Bin et al,[23] after examining 20 dentin specimens with a 3-mm round aperture spectrophotometer, found that, for 1-mm–thick human dentin, the mean TP value was 16.4. These findings suggest that large differences do not exist between the TP values of sectioned human dentin with thicknesses ranging from 0.5 to 2.0 mm. Nevertheless, in these studies, when the translucency parameter was measured, different backgrounds were used, which could lead to variations of the TP values measured. The use of different backgrounds should be

taken into account whenever the TP values of different studies are compared.

In the present study, anterior teeth dentin specimens exhibited higher L* values but lower a* and b* values against both the black and white backgrounds compared with molar dentin specimens. These results were not surprising as anterior teeth are visually lighter (higher L* values), whereas posterior teeth are darker and more chromatic (lower L* values and higher a* and b* values). Taking into account these differences between anterior and posterior human dentin, a color and translucency analysis is essential before dental restorations. Given that natural teeth have a double-layered structure whose components are interdependent in terms of their optical properties, the nature and position of each tooth inside the dental arches should be carefully considered whenever a reconstruction is undertaken.

CONCLUSIONS

Within the limitations of this in vitro study, it was concluded that important differences exist between spectrophotometric and spectroradiometric measurements of all color coordinates of the same specimen and that human dentin from anterior teeth is lighter but less translucent than molar human dentin.

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