Acta Odontologica Scandinavica, 2012; 70: 362–367

informa
healthcare

ORIGINAL ARTICLE

Influence of refractive index on optical parameters of experimental resin composites

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Abstract

Objective. Color characteristics of the experimental resin composites were determined to know the influence of different refractive index (RI) on optical parameters. ***Materials and methods.*** Four experimental light-cured resin composites of the same shade but with different RI were used. The colorimetric values of the specimens were measured against black and white backgrounds using spectrophotometry. The results were converted to CIE L*a*b* color-space values. The chroma (C*ab), color difference (ΔE), translucency parameter (TP) and opacity (OP, opposite property of TP) values were calculated. Surface gloss (GS) of the specimen was also measured. ***Results.*** The L* coordinate, a* coordinate and ΔE*ab values increased as the difference in RI increased. The OP and GS values increased and the TP values decreased as the refractive-index difference increased. The L* and C*ab values increased as the value of the RI increased. The TP, OP and GS values were highly correlated with the RI value. The TP value decreased and the OP and GS values increased, as the RI value increased. ***Conclusions.*** Refractive index of resin composites is important when thinking about improving the color appearance of esthetic restorations.

Key Words: *color, resin composites, refractive index, CIE L*a*b**

Introduction

The color of a material is influenced by various factors including the lighting conditions, translucency, opacity (OP), light scattering and surface gloss (GS) [1]. The factors that determine the color and optical properties of resin composites include the resin-matrix composition, the filler composition and content and pigments and other chemical additives [2]. Differences in the light-transmittance characteristics of resin composites of different shades can affect their clinical appearance [3]. There is an increasing demand for restorations with improved esthetic performance. Tooth-colored restorations should therefore aim to reproduce the color characteristics, including the translucency and GS, of natural teeth. Light-transmittance characteristics might have an important influence on the color of resin composites [4]. In cases of class IV dental caries, restorations sometimes have a grayish aspect in comparison with the surrounding tooth color, because the relatively translucent materials are affected by the darkness of the oral cavity [4,5]. The reflection of light from surfaces can be classified into two broad categories. The diffuse component results from light penetrating the surface, undergoing multiple reflections and refractions and re-emerging at the surface. The specular component is a surface phenomenon that can be expressed as a function of the incidence angle and the refractive index of the material, the surface roughness and a geometrical shadowing function [6]. Some portion of the incident light reflects off the background, which can affect the appearance of composite restorations [7].

The color of a resin composite is related to the scattering and absorption characteristics, light reflectivity and translucency of the material. Previous studies of the color characteristics of resin composites have

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(Received 9 March 2011; revised 27 March 2011; accepted 8 May 2011)

ISSN 0001-6357 print/ISSN 1502-3850 online
DOI: 10.3109/00016357.2011.600724

described the relationships among these properties and potential impacts of the translucency and GS of esthetic restorative materials on the clinical performance have been identified [8,9]. Understanding the relationships among these properties could therefore aid the development of esthetic materials that mimic the tooth structure.

Resin composites contain a resin matrix and fillers with various refractive indices (RI) [10,11]. The appearance of the restorative materials might therefore depend upon the contents of the resin composites. Studies have focused on the influence of the type, particle size and content of the fillers on the appearance of resin composites [12,13]. Resin composites also contain an organic matrix with a refractive index that differs from those of the inorganic fillers. The effects of the RI of the monomers on the optical properties of resin composites have not been fully explored [7]. The present study investigated the influence of the RI of the resin matrix on the color properties, including the GS, of experimental resin composites. The null hypothesis was that the RI of the experimental resin composites with different RI values did not affect the color properties, including CIE L*a*b*, chroma (C*ab), color difference (ΔE*ab), translucency parameter (TP), OP and GS.

Materials and methods

The experimental resins contained bisphenol-a-glycidyl methacrylate (Bis-GMA, Shin-Nakamura Chemical Co., Wakayama, Japan) and triethylene glycol dimethacrylate (TEGDMA, Shin-Nakamura Chemical Co.) mixed at a mass ratio of 38:62, 54:46, 71:29 or 87:13 (Shofu Inc., Kyoto, Japan). The photoinitiator chemistry of all monomers was based on camphorquinone (0.3 wt%, Tokyo Chemical Industry, Tokyo, Japan) and an amine, *p*-dimethylaminobenzoic acid ethyl ester (0.3 wt%). Aluminosilicate glass fillers treated with γ-methacryloyloxypropyl trimethoxysilane (average particle size of 1.0 μm, Shofu Inc.) were used to make 68.2 wt% filler-loading resin composites (Table I).

The RI of the four experimental resin composites were measured with an Abbe refractometer (NAR-2T; Atago Co., Tokyo, Japan) at 23 ± 1°C [14]. Resin pastes were irradiated with a curing unit (Optilux 501; SDS Kerr, Orange, CA) and the RI of the resultant polymers were measured 1 day after irradiation. The RI of the fillers were confirmed by the Becke-line method, in a series of index-matching solutions (tricresyl phosphate and dioctyl adipate), using a polarizing microscope (Eclipse LV100POL; Nikon Corp., Tokyo, Japan).

Standardized specimens were prepared using a 3.5-mm-thick (for the gloss measurement) or 1.0-mm-thick (for the color measurement) acrylic, round box-shaped mold with a 10.0-mm-diameter hole. Each resin composite was poured into the mold, covered with a clear plastic film and light irradiated for 30 s using the curing unit with a light intensity of 800 mW/cm^2. The resin disk was then removed from the mold and the bottom surface was light irradiated for 30 s. Four disks were prepared for each of the resin composites, and the surfaces of the specimens were not polished after curing. The disks were stored at 23 ± 1°C in a dark room for 24 h.

The color measurements were performed using a spectrophotometer (CMS-35F S/C; Murakami Color Research Laboratory Co., Tokyo, Japan) with a Flexible Sensor (FS-3, Murakami Color Research Laboratory Co.). The diameter of the illumination area was 6 mm and the diameter of the area that received light from the object was 3.0 mm. The International Commission on Illumination Standard Illuminant D65 (CIE D_{65}) was used as a light source for the spectrophotometer and the illuminating and viewing configurations were set at CIE 45°/d. The color was measured in the reflectance mode over the white (Y = 90.56, X = 92.14, Z = 110.90) and black (Y = 0.01, X = 0.01, Z = 0.01) backgrounds. All of the standard deviations for the XYZ values of the white and black background were less than 0.01. For all color measurements, the spectral reflectance was measured at wavelengths ranging from 380–740 nm, with 2-nm intervals, and subsequently converted to CIE L*a*b* and CIE L*C*H* (lightness, chroma, hue) values. The measurements were repeated three times for each specimen.

The C*ab was calculated using the following equation [15]:

$$C^*ab = (a^{*2} + b^{*2})^{1/2}.$$

Table I. Refractive index and monomer composition of experimental resin composites.

	Refractive index			
Composite	Polymer	Filler	Bis-GMA (wt%)	TEGDMA (wt%)
A	1.525	1.525	38	62
B	1.540	1.525	54	46
C	1.555	1.525	71	29
D	1.560	1.525	87	13

The ΔE*ab between the values measured for composite A and for the other three samples (composites B–D) was calculated as follows [15]:

$$\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}.$$

The transparency (TP) was calculated using the following equation [16]:

$$TP = [(L_B^* - L_W^*)^2 + (a_B^* - a_W^*)^2 + (b_B^* - b_W^*)^2]^{1/2}.$$

Here, the subscript letters 'B' and 'W' refer to the color coordinates over the black and white backgrounds, respectively.

In order to indicate the translucency parameters of the specimens, the OP was calculated using the following equation [6]:

$$OP\,(\%) = 100 \times (Y_B / Y_w).$$

Here, Y_B is a Y-value backed by a light trap and Y_W is a Y-value backed by a white-colored plate.

The GS of the specimen was measured with a gloss meter (GM-26D; Murakami Color Research Laboratory Co.) and was expressed in gloss units. The gloss meter was calibrated before each measurement using a standard black board with a reference value of 92.1 at a 60° incidence angle. The measurements were repeated three times for each specimen.

To determine the influence of the refractive indices of the experimental resin composites on the optical parameters, the value of the Pearson's correlation coefficient (R) between the refractive index and the color parameters was calculated by linear-regression analysis.

The data for each group were tested for homogeneity of variance using Bartlett's test and then subjected to one-way analysis of variance (ANOVA) followed by Tukey's honestly significant difference (HSD) test at $\alpha = 0.05$. Sigma Stat statistical software (Version 3.1; SPSS, Chicago, IL) was used for the calculations and analysis.

Results

The color parameter and GS values of the experimental resin composites are shown in Table II. The L*(77.4 ~ 78.9), a*(0.4 ~ 0.9) and ΔE*ab (0.0 ~ 2.4) values increased as the RI difference increased. On the other hand, b* (16.1 ~ 17.5) and C*ab (16.1 ~ 18.0) values remain in contrast regardless of the differences in RI values. The OP (30.0 ~ 57.2%) and GS (81.2 ~ 88.7) values increased and the TP (39.4 ~ 23.3) values decreased significantly, as the RI difference increased.

The results of the linear-regression analysis and the R values between the RI and color parameters (L*, C*ab, TP, OP and GS) are shown in Figure 1. The L* and C*ab values increased as the value of the refractive index increased (r = 0.702 and 0.551, respectively). The TP, OP and GS values were highly correlated with the refractive index value ($r = 0.979 \sim 0.986$). The TP value decreased, whereas the OP and GS values increased as the refractive index value increased.

Discussion

Resin composites are optically translucent media comprising a highly transparent base resin, small filler particles and other additives. When a white incident light is transmitted through a resin composite, it is scattered by the small filler particles before it emerges and reaches the eye of an observer, which affects the perceived optical and color characteristics. The color of a material is determined by a complex combination of its optical properties [17,18]. The light-transmittance and reflectance characteristics have an important influence on the color of composite resins [8]. In the present study, the L* and C*ab values were significantly correlated with the refractive index of the experimental resin composite ($r = 0.551$–0.702) and the TP, OP and GS values were highly correlated with the refractive index values ($r = 0.979$–0.986). We therefore rejected the null-hypothesis that the refractive index of the resin composite did not affect the color properties selected in this study.

There is some debate as to the threshold value of color difference that can be visually perceived. The

Table II. Color parameters and surface gloss of experimental resin composites.

Composite	L*	a*	b*	C*ab	ΔE*ab	TP	OP(%)	GS
A	77.4 (0.4)	0.4 (0.1)	16.1 (0.3)	16.1 (0.3)	0.0 (0.0)	39.4 (1.1)	30.0 (1.3)	81.2 (0.6)
B	78.1 (0.8)	0.5 (0.1)	16.8 (0.7)	16.8 (0.7)	1.8 (0.9)	33.6 (1.3)	39.2 (1.1)	83.2 (0.3)
C	78.7 (0.5)	0.6 (0.1)	17.5 (0.5)	18.0 (0.7)	2.4 (0.3)	27.3 (0.3)	48.6 (0.2)	87.6 (0.5)
D	78.9 (0.9)	0.9 (0.1)	16.5 (0.4)	16.8 (0.5)	2.0 (0.6)	23.3 (0.4)	57.2 (0.6)	88.7 (0.4)

n = 4, values in parentheses indicate standard deviations.
Values connected by horizontal lines indicate no significant different (Tukey HSD test, $p > 0.05$).

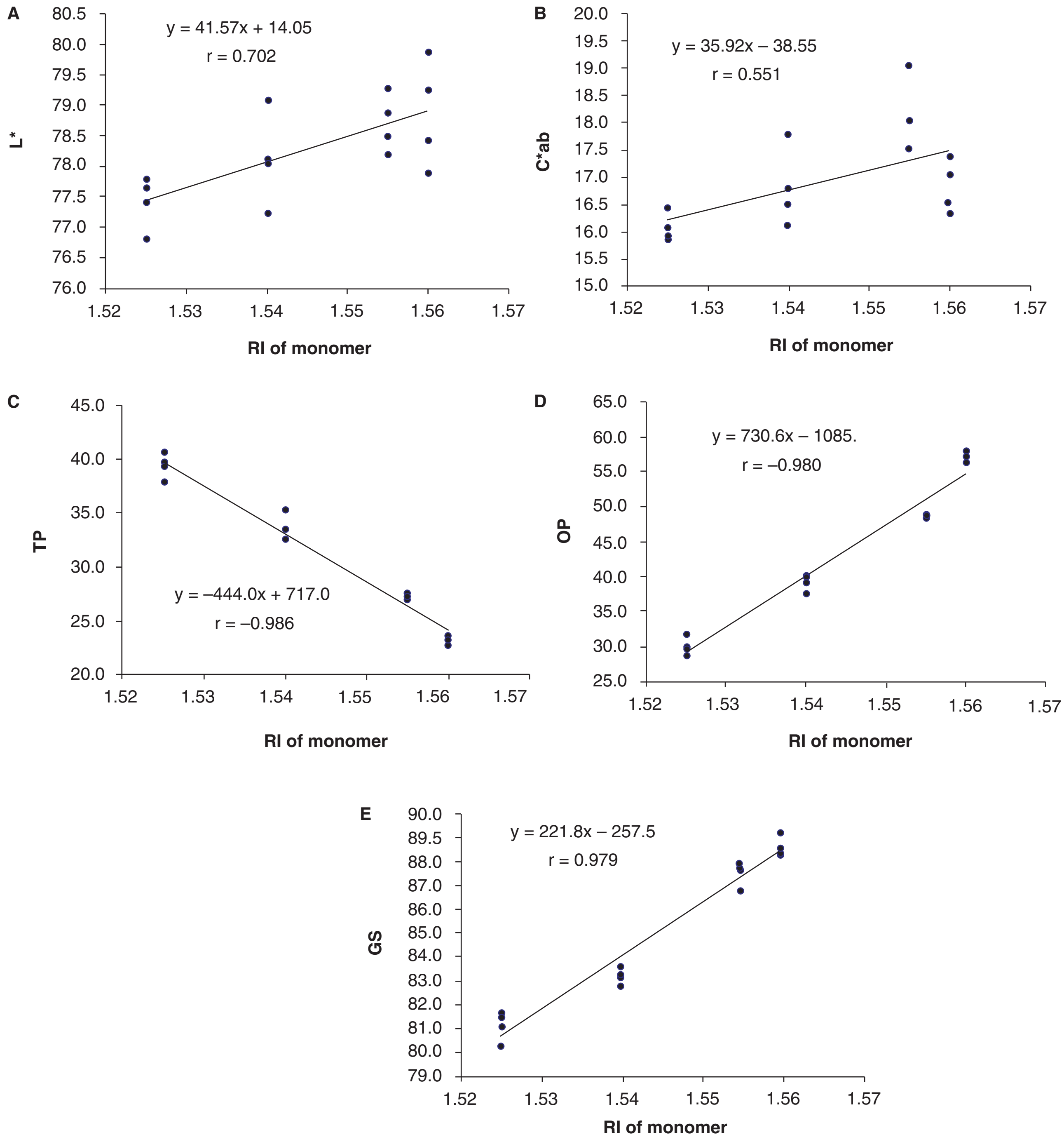

Figure 1. The results of linear regression analysis and Pearson's correlation coefficients between the refractive index and (A) L*values ($R = 0.702$), (B) C*values ($R = 0.551$), (C) TP values ($R = 0.986$), (D) OP values ($R = 0.980$) and (E) GS values ($R = 0.979$). L* and C*ab values increased as the value of refractive index increased. TP, OP and GS values were highly correlated with refractive index value.

relationships between instrumentally measured color differences (ΔE*ab) and assessments of color differences by human observers were studied previously. The results showed that the acceptability thresholds of color differences were 1.1 for red-varying shades and 2.1 for yellow-varying shades and the thresholds for perceptibility judgments were significantly lower than those for acceptability judgments [19]. In contrast, a clinical study of human observations and colorimetry reported that restorations that were judged to be clinically acceptable *in vitro* for color match had an average ΔE*ab of 3.7 [20]. In another clinical study, 50% of the observers rated sample pairs of dental composite resins as unacceptable when the ΔE*ab was ~ 3.3 [21]. In the present study, the color differences between composite A and the other experimental resin composites ranged from 1.8 (for composite B) to 2.4 (for composite C) and could be perceived by the naked eye. In this comparison, the differences in ΔE*ab value might have been caused by differences in the refractive indices of the resin composites. The L*, a*, b* and ΔE*ab values of objects can be affected by various factors including the measurement apparatus, background color, illumination and object size.

The appearance of a restoration is strongly influenced by the color, GS and translucency of the material. Both surface reflection and vertical attenuation affect the absorption and scattering of light within a material [22,23]. The reflection of light from the surface of restorative materials can be classified into two broad categories. The diffuse component results from light penetrating the surface, undergoing multiple reflections and refractions and then re-emerging at the surface. The specula component is a surface phenomenon that can be expressed as a function of the incidence angle and the RI of the material, the surface roughness and a geometrical shadowing function. It has been reported that the color and translucency of esthetic restorative materials were determined not only by macroscopic phenomena (such as the matrix and filler compositions and the filler content), but also by relatively minor pigments and, potentially, the other chemical components of the materials [6]. The influence of translucency on the shade of resin composites requires further investigation.

The optical properties of a resin composite consisting of two different transparent base monomers and small filler particles are characterized by the differences in optical properties between these components. In particular, differences in the RI might be critical in determining the optical properties of resin composites. Differences in the optical properties and color appearance of materials were expected to be dominated by differences in the RI of the filler particles and resin matrix. In the current study, greater RI differences between the inorganic fillers and the matrix phase of the resin composites led to a greater OP of the materials, due to multiple reflection and refraction at the matrix–filler interfaces. This tendency was in agreement with the results of a previous study [24,25]. The color and translucency of esthetic restorative materials are determined not only by macroscopic phenomena (such as the matrix and filler compositions and the filler content), but also by relatively minor pigments and, potentially, the other chemical components of these materials [26].

In the present study, the RI was strongly correlated with the OP and TP. This suggested that the color appearance of the esthetic translucent materials depended upon the RI of the components. As the RI difference between the resin and the filler decreased, the transparency improved and the OP decreased. In addition to the filler refractive index and loading level, the filler morphology, including the size and distribution of filler particles, affects the optical properties [27]. Even in the absence of fillers, the optical properties of monomers change during polymerization as the RI rise that accompanies polymerization and light scattering is associated with gelation and vitrification [28]. A linear correlation has been reported between the percentage of bis-GMA in the resin matrix and the translucency of the material [22]. The difference in translucency could be due to the fact that bis-GMA has a refractive index closer to that of the silica filler than that of TEGDMA. The chemical structural features of bis-GMA affect critical factors including the viscosity, diffusivity, polymerization shrinkage, mechanical properties and optical properties of resin composites.

The color of a composite material is determined by a complex combination of optical properties within the material. To date, this has not been fully explored either theoretically or experimentally and further investigation of the precise relationship between the color and the r RI is required. Within the limitations of the present study, the RI was shown to affect the color parameters of the resin composites as well as the GS, which originates from the geometrical distribution of light reflected by the surface [29,30]. The surface roughness and GS of composite resins are affected by brushing and abrasive media. It could thus be beneficial to focus on the potential of the RI in order to improve the color appearance of composite resins.

Acknowledgement

This work was supported, in part, by Grant-in-Aid for Scientific Research (C) number 20592237 from the Japan Society for the Promotion of Science (JSPS), by the Sato Fund, and by a Grant from the Dental Research Center, Nihon University School of Dentistry, Japan.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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