Journal of Dentistry 126 (2022) 104316

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.elsevier.com/locate/jdent

Relevant optical properties for gingiva-colored resin-based composites

Cristina Lucena [a], Cristina Benavides-Reyes [a], Javier Ruiz-López [b], Maria Tejada-Casado [b], Rosa Pulgar [a], María M. Pérez [b,*]

[a] Department of Stomatology, Faculty of Dentistry, Colegio Máximo, Campus de Cartuja s/n. University of Granada. 18071. Granada. Spain
[b] Department of Optics, Faculty of Science, Campus Fuentenueva, Edificio Mecenas, s/n. University of Granada. 18071. Granada, Spain

ARTICLE INFO

Keywords:
Gingiva-colored resin-based composite
Translucency
Scattering
Absorption
Transmittance

ABSTRACT

Objectives: To evaluate the optical properties of gingiva-colored resin-based composites (GCRBCs).
Methods: Five discs (8 mm diameter x 1mm height) of 17 shades of GCRBCs were prepared. Diffuse reflectance was measured against white and black backgrounds using a calibrated spectroradiometer, CIE D65 illuminant and the CIE 45°/0° geometry. Relative translucency parameter was calculated using ΔE_{00} (RTP_{00}). Translucency differences were evaluated using published data of 50:50% translucency perceptibility (TPT_{00}) and acceptability (TAT_{00}) thresholds. Scattering (S) and absorption (K) coefficients and transmittance (T%) were calculated using Kubelka–Munk's equations. Data were statistically analyzed using Kruskal–Wallis, Mann–Whitney tests, and VAF coefficient.
Results: The RTP_{00} values of the 17 evaluated shades ranged from 8.69 to 21.34. There were perceptible translucency differences (TPT_{00}=0.62) between different shades of the same brand and between composites designated with the same shade of different brands. Spectral distributions of S, K and T were wavelength-dependent. Although the spectral behavior of the S and K coefficients and T% were similar for all the gingival composites evaluated, the values of these parameters presented statistically significant differences between shades, which would justify the differences found in the relative translucency parameter.
Conclusions: The optical properties S, K and T% of GCRBCs were significantly different, resulting in perceptible translucency differences between the same shade of different commercial brands and between different shades of the same brand.
Clinical significance: Translucency differences of gingiva-colored composites may significantly influence their masking ability affecting the clinician's choice of restorative material.

1. Introduction

Gingival recession affects a significant proportion of the adult population [1]. Apical migration of the gingival margin contributes to the retention of food debris and could alter the dental and periodontal tissues [2]. Although gingival defects are sometimes asymptomatic [3], often present esthetic concerns because of the disproportion between height and width of the visible crown [4].

The loss of gingival tissue can be treated from surgical, orthodontic or prosthetic approaches, sometimes requiring a multidisciplinary treatment [1] and being a challenge for the dentist to achieve a natural appearance [5]. Gingiva-colored resin-based composites (GCRBCs) have been proposed as a cost-effective and minimally-invasive alternative for masking the effects of gingival recession [3,6]. This conservative treatment is especially valuable for patients with a questionable prognosis of surgery or surgical contraindications [4].

Although many GCRBCs have been currently introduced, the scientific information is scarce and mainly refers to laboratory composites for indirect techniques [7–10].

Regarding GCRBCs for direct techniques, previous research indicates good adhesion to various substrates [11] and adequate wear resistance [12], but data are inconsistent with esthetic results. Authors of a clinical case report found some difficulties in mimicking gingival colors and patterns when using GCRBCs, particularly for lesions that extended close to the attached gingiva [13]. On the other hand, a few clinical studies [2, 14] reported high esthetic outcomes of direct GCRBC restorations in treating multiple gingival recessions, even though the esthetic success was visually and short-term evaluated. Finally, according to an

* Corresponding author at: María M. Pérez. Department of Optics, Faculty of Science, Campus Fuentenueva, Edificio Mecenas, s/n. University of Granada. 18071. Granada, Spain
E-mail address: mmperez@ugr.es (M.M. Pérez).

https://doi.org/10.1016/j.jdent.2022.104316
Received 31 July 2022; Received in revised form 18 September 2022; Accepted 30 September 2022
Available online 3 October 2022

experimental research [9], the shade match between two GCRBCs (Gradia (GC Europe, Leuven, Belgium) and Ceramage Gum (Shofu, Kyoto, Japan)) and the healthy gingiva of 238 subjects was low. Thus, the mean color differences reported were greater than the 50: 50% CIELAB and CIEDE2000 acceptability thresholds [15,16]. However, only the base shades of each restorative material were tested, so adding modifiers or stains could improve the shade match in clinical situations.

Natural appearance of resin-based composite restorations requires not only the matching of color (value, hue and chroma) but also the blending of their specific optical characteristics: specular light reflection and diffuse light reflection at the resin composite surface; absorption and scattering of light within the resin composite; transmission of the light flux through material [17]. Therefore, for optimal esthetic results, both adequate shade and optical properties of the restoration are of extreme importance.

Kubelka–Munk (K–M) reflectance theory is a mathematical model describing the reflectance resulting from two-flux radiation transfer in a homogenous and uniform medium placed over an opaque backing [18]. The main advantage of this theory is that the absorption and scattering coefficients (K and S, respectively) can be easily expressed as a function of the reflectance and transmittance of the sample. Several authors [19,20] have reported on the relationship between Kubelka–Munk S and K coefficients and the μ_s and μ_a coefficients. However, previous studies used the reflectance measurements based on the K–M reflectance theory to calculate the optical properties of dental tissues and materials, such as human enamel and dentin [21,22] and indirect [23,24] and direct [25,26] restorative materials. A study showed that corrected K–M reflectance theory may be used to accurately quantify the optical K–M coefficients of dental resin-based composites [27].

In addition, because of its translucent nature, the final aspect of tooth-colored resin-based composite restorations depends on both the color of underlying tissue and the translucency of the restorative material [28,29].

The translucency of a material may be characterized by the translucency parameter (TP) [30,31]. It is defined as the color difference of a material that is optically uniform throughout its thickness and which is in optical contact with ideal white ($R_g = 1$) and black background ($R_g = 0$). Under these conditions, TP values of 0 and 100 would correspond to completely opaque and completely transparent materials, respectively [32]. However, when the backgrounds used are not ideal, referred to the color of the backings used in the color difference determinations, the relative translucency parameter (RTP) is required [33]. In this case, there will be a change in scale, being the maximum possible TP obtained the color difference between the backings used. Moreover, the use of the CIEDE2000 color difference formula has been suggested for TP calculation [34,35].

Actually, there is no information on the translucency and optical properties of gingiva-colored resin-based composites, which justifies further studies. This information is important to the successful management of the GCRBCs, and to satisfy the increased aesthetic demands of patients. Therefore, the purpose of this study was to use K-M theory to evaluate the scattering, absorption and transmittance, and evaluate the relative translucency parameter (RTP) of contemporary GCRBCs. The null hypothesis is that there are no statistically significant differences in

Table 1
Information on the gingiva-colored resin-based composites evaluated in the study. All resin-based composites data were provided by manufacturers.

Material	Manufacturer	Shade (Code)	Batch n°	Composition	Type	Filler content wt%/vol%
Renamel Gingafill	Cosmedent (Chicago, USA)	Light Pink **(RGL)**	1646208	Monomers: UDMA, BBDMA. Fillers: silicon dioxide and prepolymerized composite (70%), initiators, stabilizers and pigments (< 1%). Particle size: 0.04- 0.2 μm.	Sculptable Microfilled	70%/60%
		Medium Pink **(RGM)**	1646218			
		Dark Pink **(RGD)**	161908A			
PermFlo® Pink	Ultradent (South Jordan, Utah, USA)	Pink **(PFP)**	BH2V6	Monomers: TEGDMA, BisGMA, UDMA. Fillers: Sodium Monofluorophosphate. Particle size: 1 μm.	Flowable	68%/NC
AnaxGUM	Anaxdent GmbH (Stuttgard, Germany)	Light Pink **(AXL)**	2019006786	Monomers: UDMA, BDDMA, BisGMA. Fillers: anorganic fillers, pyrogenic silica, initiators, stabilizers, pigments. Particle size: 0.04- 0.7 μm.	Sculptable Microfilled	74%/NC
		Dark Pink **(AXD)**	2020001998			
		Orange Pink **(AXO)**	2020001526			
		Purple Pink **(AXP)**	2019006922			
		Brown Pink **(AXB)**	2011008860			
Amaris® Gingiva	VOCO GmbH (Cuxhaven, Germany)	Natural Pink **(AMN)**	1932473	Monomers: BisGMA, UDMA, TEGDMA. Fillers: silane coated glass ceramic, pre-polymerized filler, silica nano particles.	Sculptable Nanohybrid	80%/NC
Venus Pearl Gum	Kulzer GmbH (Hanau, Germany)	Gum **(VPG)**	K010030	Monomers: UDMA, EGDMA, TCD-DI-HEA Fillers: Barium Aluminium-boro-fluor Silicate Glass, Silica, Polymer, Titanium dioxide, fluorescent pigments, metallic oxide pigments, organic pigments, aminobenzoicacidester, BHT, Camphorquinone.	Flowable Nanohybrid	NC/59%
Beautifil II Gingiva	Shofu Dental (Kyoto, Japan)	Light **(BGL)**	032013	Monomers: BisGMA, TEGDMA Fillers: S-PRG Aluminium-fluor-borosilicate glass. Pigments, others	Sculptable Nanohybrid	60-70%
		Dark **(BGD)**	032012			
		Orange **(BGO)**	121904			
		Violet **(BGV)**	121904			
		Brown **(BGB)**	121905			
		Gum **(BGG)**	091916		Flowable Nanohybrid	

NC: Information not collected. **UDMA**: urethane dimethacrylate; **BBDMA**: 1,4-Butanediol dimethacrylate; **TEGDMA**: Triethylene glycol dimethacrylate, **BisGMA**: bisphenol-A-glycidyldimethacrylate; **EGDMA**: Ethylene glycol dimethacrylate, **TCD-DI-HEA:** 2-propenoic acid, (octahydro-4,7 methano-1H-indene-5-diyl) bis (methyleneiminocarbonyloxy-2,1-ethanediyl) ester; **BHT:** butylated hydroxytoluene; **S-PRG:** surface pre-reacted glass ionomer.*2.2. Spectral reflectance* optical properties and relative translucency parameter among the GCRBCs evaluated.

2. Materials and methods

2.1. Sample preparation

The information of the materials used in this study is shown in Table 1. Five discs of each shade of each GCRBC system were prepared using a mold of Tygon® tube (8 mm diameter x 1mm height). The mold was placed on a glass slide (1mm thickness), covered with a transparent polyester Mylar strip on the top and bottom, to prevent oxygen inhibition and obtain a smooth clinically relevant surface finish [36]. The resin-based composite was inserted into the mold and pressed firmly with another glass slide. Light-activation (Bluephase Style, Ivoclar-Vivadent, Schaan, Liechtenstein; 1100 mW/cm^2) was carried out according to the manufacturer's instructions, placing the 10 mm light-curing tip on the glass slide. Irradiance of light-curing unit was controlled with his own radiometer (Bluephase Meter II, Ivoclar-Vivadent).

All specimens were examined for surface defects under magnification (10 ×). Discs thickness (1.00± 0.05 mm thick) were verified using a digital caliper (Mitutoyo, Europe GmbH, Germany) measuring at three different locations. Before spectral reflectance measurements, specimens were stored in 37°C distilled water for 24 h in a dark chamber.

2.2. Spectral reflectance

A non-contact measuring system consisting of a spectroradiometer (PR 670- Photo Research, Chatsworth, CA, USA) and two fiber-optic light cables (Model 70050; Newport Stratford Inc., Franklin, MA, USA), with a xenon arc lamp (300W, Newport Stratford Inc., Franklin, MA, USA) on a custom-made optical table was used to measure spectral reflectance. The spectroradiometer was placed away from the samples (40 cm) with the illuminating/measuring geometry corresponding to CIE 45°/0°. Values of spectral reflectance for wavelengths at 2 nm were obtained from 380 to 780 nm with a focus measuring aperture of 1° at the center of each disc. The spectral reflectance of all specimens was measured against both white (L* = 94.2, a* = 1.3 and b* = 1.7) and black (L* = 3.1, a* = 0.7 and b* = 2.4) 50 × 50 mm ceramic tile backgrounds (Ceram, Staffordshire, UK). Saturated sucrose solution having an index of refraction of approximately 1.5 was placed as the optical contact between specimen and background [25,27]. Three repeated reflectance measurements without replacement were performed, and the results were averaged.

2.3.Relative. translucency parameter (RTP)

Spectral reflectance values were converted into CIE L*a*b* color coordinates using the CIE 2° Standard Observer and the CIE D65 Standard Illuminant to compute the relative translucency parameter (RTP).

RTP_{00} values were determined by calculating the color difference between readings over the black and the white backgrounds according to the CIEDE2000 (1:1:1) color difference formula [37,38]:

$$RTP_{00} = \left[\left(\frac{L'_B - L'_W}{k_L S_L}\right)^2 + \left(\frac{C'_B - C'_W}{k_C S_C}\right)^2 + \left(\frac{H'_B - H'_W}{k_H S_H}\right)^2 + R_T\left(\frac{C'_B - C'_W}{k_C S_C}\right)\left(\frac{H'_B - H'_W}{k_H S_H}\right)\right]^{1/2}$$

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. The weighting functions (S_L, S_C and S_H) adjust the total color difference for variation in the location of the color difference pair in L', a', b' coordinates. The parametric factors (k_L, k_C and k_H) are correction terms for experimental conditions. The values for parametric factors used in the present study were $k_L = k_C = k_H = 1$ (RTP_{00} (1:1:1)). Finally, the rotation function (R_T) accounts for the interaction between chroma and hue differences in the blue region [37,38].

Translucency differences were evaluated finally using published data of 50:50% translucency perceptibility (TPT_{00}=0.62) and acceptability (TAT_{00} =2.62) thresholds [35].

2.4. Kubelka-Munk coefficients

The Kubelka-Munk transmittance (T%), and scattering (S) and absorption (K) coefficients were calculated algebraically as previously described [27]. These optical parameters are wavelength-dependent, hence, their values vary across the visible spectrum.

2.5. Statistical analysis

To analyze the variations in RTP_{00} parameter, S and K coefficients and T% between the GCRBCs studied, the homogeneity of variance was studied using Levene's test (α= 0.05). Since equal variances could not be assumed, the Kruskal-Wallis test one-way analysis of variance by ranks was applied. Mann Whitney U test with a Bonferroni correction ($p<0.001$) was performed for pair-wise comparisons between shades of the same brands and among shades of different GCRBC brands. Statistical analysis was performed using standard statistical software (SPSS Statistics 20.0.0, IBM Armonk, NY, USA).

In addition, to determine the level of similarity regarding spectral behavior of Kubelka-Munk coefficients, the VAF (Variance Accounting For) coefficient with Cauchy-Schwarz inequality was used as follows:

$$VAF = \frac{\left(\sum_{k=380}^{780} a_k . b_k\right)^2}{\left(\sum_{k=380}^{780} a_k^2\right)\left(\sum_{k=380}^{780} b_k^2\right)}$$

where a_k is the spectral value for T%, K and S coefficients (from 380-780 nm) and b_k is the equivalent for another measurement. The closer this coefficient gets to unity (100%), the more similar the two curves become.

3. Results

3.1. Relative translucency parameter

Fig. 1 shows the means and standard deviations of RTP_{00} of all materials evaluated. Amaris Gingiva nature (AMN) and the dark shade of Renamel Gingafill (RGD) showed, respectively, the highest and the lowest translucency values, with significant differences between them ($p<0.001$).

Fig. 2 shows the translucency differences (ΔRTP_{00}) among different shades from the same brand (2a) and similar shades (i.e., same label) of different brands (2b) of GCRBC.

Translucency differences (ΔRTP_{00}) among different shades of the same brand were above of the TPT_{00} for all materials, except among shades AXO-AXB (ΔRTP_{00}=0.17 units) of AnaxGUM, and BGL- BGO (ΔRTP_{00}=0.21 units), BGD-BGL (ΔRTP_{00}=0.26 units), BGD-BGO

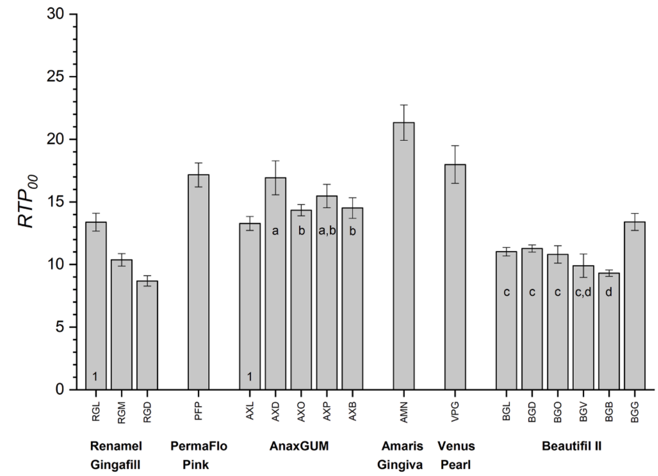

Fig. 1. RTP_{00} of gingiva colored resin-based composites evaluated.
** For the pair-wise comparisons among different shades from the same GCRBC brand, the same lowercase letter indicates no significant differences in RTP_{00}. For the pair-wise comparisons between similar shades from different brands the same number indicates no significant differences in RTP_{00}.*

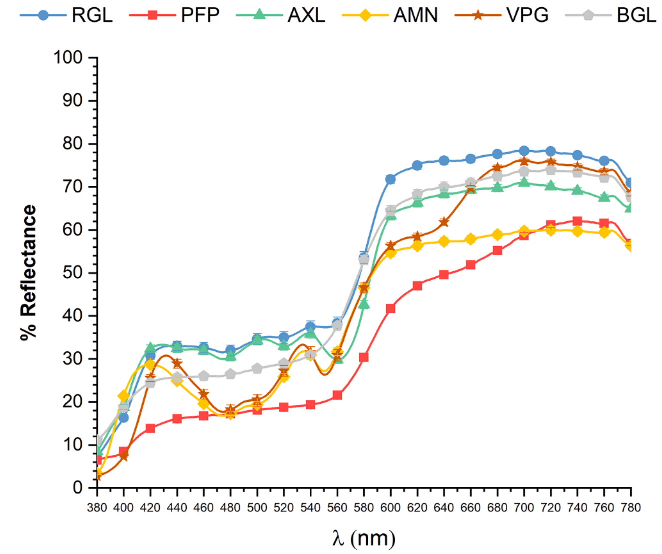

Fig. 3. Spectral reflectance of the lightest shades (greater L*) of each brand of GCRBC.

(ΔRTP_{00}=0.47 units) and BGB-BGV (ΔRTP_{00}=0.59 units) of Beautifull II Gingiva.

The "light" shades from different brands had a similar translucency (p> 0.001) except for BGL, whose RTP_{00} was the lowest of all light shades (Fig. 1). However, all the ΔRTP_{00} between the "light" shades were below TAT_{00} (Fig. 2b). On the contrary, RTP_{00} comparisons between same-labeled shades from different brands ((1) dark; (2) orange; (3) brown and (4) purple/violet) have shown significant differences (p<0.001). In addition, ΔRTP_{00} was mostly higher than the TAT_{00} (Fig. 2b).

3.2. Optical properties

Fig. 3 presents the spectral reflectance (against white background) of the lightest shades (greater L*) of each brand of GCRBC. The VAF analysis showed similar spectral reflectance behavior for all GCRBCs (VAF>92.26%), with a slight increase of the spectral reflectance value from 380 to 580nm, then an abrupt ramp-up to 630nm and stabilization of values until 740nm. Also, AMN y VPG showed a smooth oscillation in the 440-540nn spectral interval.

Fig. 4a-d show the spectral distribution of S and K coefficients, K/S ratio, and T% as a function of wavelength for the most lightness shades (greater L*) of each brand of GCRBC evaluated.

The spectral behavior of S coefficient is shown in Fig. 4a. Overall there is a first maximum value of S between 420 and 430nm, and a second maximum near to 610nm, although for PermaFlo Pink (PFP), both "peaks" are less noticeable. Despite all GCRBCs evaluated showed a similar spectral behavior of S (91.97% ≤ VAF ≤ 99.81%), the values of scattering coefficient presented significant differences between shades from different brands (p<0.001).

The spectral behavior of K coefficient (Fig. 4b) was also similar for all materials (89.53% ≤ VAF ≤ 99.75%). Overall, the values of K decreased with increases the wavelength. Venus Pearl Gum (VPG) and AMN showed a smooth oscillation in the 440 and 560 of spectrum range. Also, the values of K were statistically different (p<0.001) except between VPG-AXL (p=0.467) and AXL and BGL (p=0.837).

Fig. 4c shows the K/S ratio for the lightest shades of each brand of GCRBC evaluated. The K/S ratio was higher for shorter wavelengths, decreased as the wavelength increased up to approximately 600nm, and

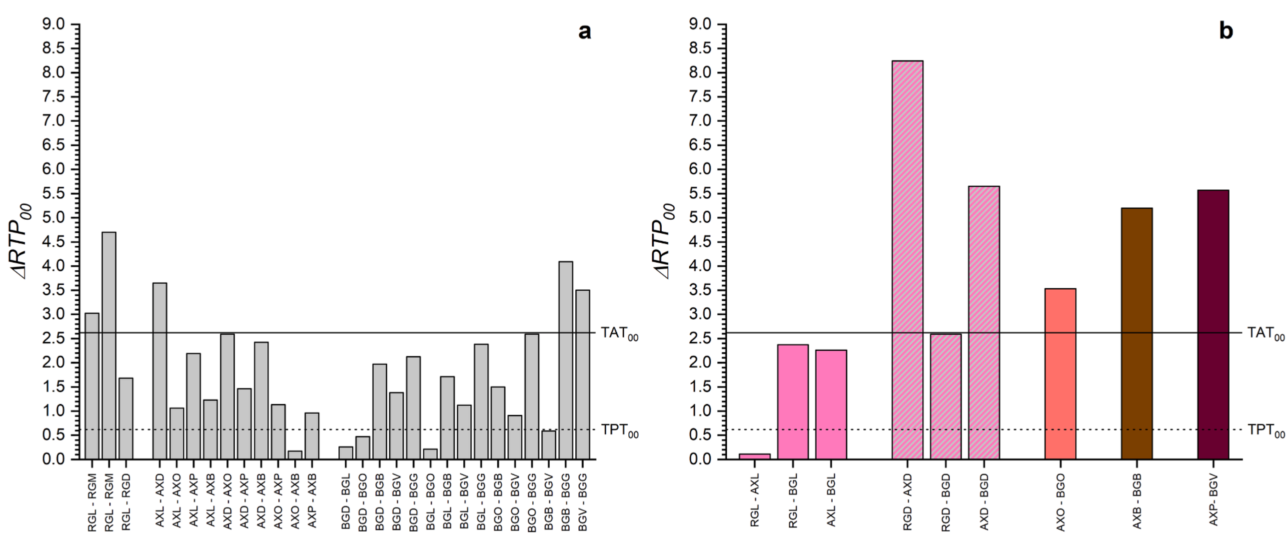

Fig. 2. Relative Translucency Parameter differences (ΔRTP_{00}). 2a. ΔRTP_{00} among different shades of the same GCRBC brand. 2b. ΔRTP_{00} between same labeled shades of different GCRBC brands.

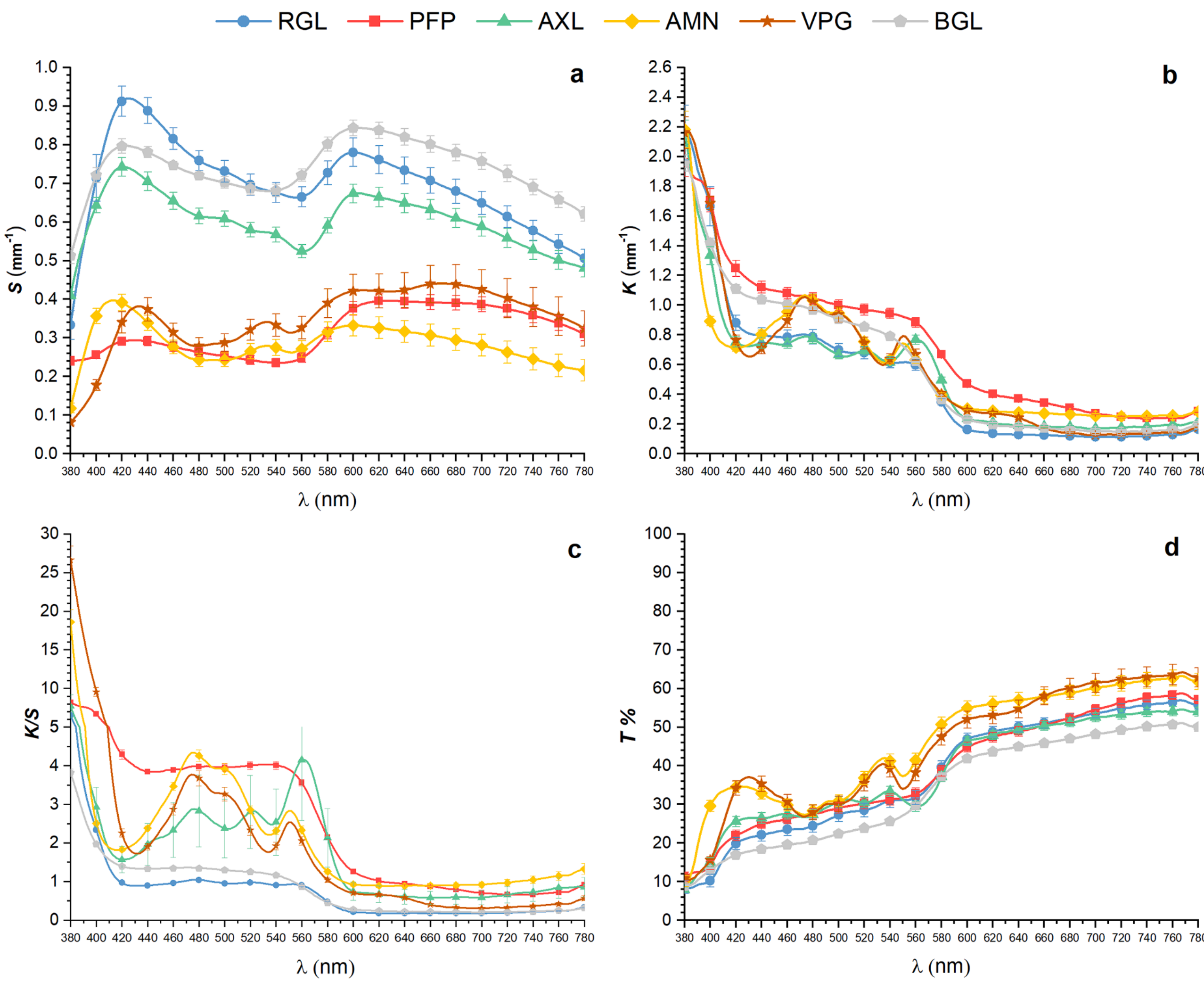

Fig. 4. Mean values of scattering (S) and absorption (K) coefficients, K/S ratio and transmittance (T%) for the most lightness shades of each brand of GCRBC. a. S; b. K; c. K/S; d; T%.

kept a constant behavior for long wavelengths. This result shows a strong prevalence of absorption over scattering for short and medium wavelengths, and dominance of scattering over absorption for long wavelengths (ratio $K/S < 1$).

Finally, Fig. 4d shows the values of transmittance as a function of wavelength. The spectral behavior of T% increased with wavelength presenting higher values for long wavelengths. Although all materials showed similar spectral behavior ($90.21\% \leq VAF \leq 99.55\%$), the values of T% were statistically different ($p<0.001$) except comparisons made between RGL-PFP ($p=0.050$), RGL-AXL ($p=0.653$), AXL-PFP ($p=0.322$) and VPG-AMN ($p=0.343$).

4. Discussion

Understanding the optical properties of the gingival composites and the factors that can affect them is essential to achieve clinical success [39]. The results of the present research show statistically significant differences in translucency and optical properties among the gingiva-colored resin-based composites evaluated. Therefore, the null hypothesis is rejected.

Translucency is an important optical property of materials that enables them to mimic surrounding structures [40], and the translucency parameter TP_{ab} [31] has been extensively used to assess the translucency of dental materials [41–43]. However, the CIEDE2000 color difference formula demonstrated a consistently better fit than the CIELAB formula in evaluating translucency thresholds [35]. In our study, RTP_{00} and the 50:50% perceptibility (TPT_{00}) and acceptability (TAT_{00}) thresholds [35] were used to interpret data on translucency differences. The thresholds [35] associated with translucency were based on visual judgments made on tooth-colored resin-based composites. However, in the quoted experiment, the observers were asked in translucency but not about color differences; therefore, these thresholds could also be applied on gingiva-colored resin-based composites.

According to our results (Fig. 1), the RTP_{00} values of the evaluated shades ranged from 8.69 to 21.34, depending on the brand and shade. It is difficult to compare these results since there are no publications on translucency of gingiva-colored composites. Furthermore, only a few publications on tooth-colored restorative materials used an experimental protocol similar to the used in this research (specimen thickness, illuminating/measuring geometry or translucency parameter) [25,44]. A recent study [25] reported TP_{00} values higher than 15.36 for 1mm thickness specimens of various tooth-colored composites. On the contrary, the TP_{00} of multi-layered zirconia specimens (1 mm thickness) ranged (depending on the sintering temperature used) from 7.5 to 8.6 and from 7.2 to 9.11 for A2 and A3 shades, respectively, [44]. Therefore, most of the shades evaluated are less translucent than tooth-colored composites (Fig. 1), which is consistent with their different clinical indication. In addition, the translucency of some shades (RGD and BGB) of gingiva-colored composites is comparable to that described for the third generation of zirconia materials [44]. This characteristic is reasonable because these composites try to imitate the gum color and for this, it is necessary to mask the white dental substrate.

Translucency depends on the relative ratio between the light scattering and light absorption phenomena occurring within the material. For tooth colored resin based composites the scattering is mainly determined by the filler particles' size [26] and shape [45], while absorption is linked to the resin matrix and the presence and nature of colorant pigments [39]. These factors determine the difference between the refractive indices of the organic matrix and the filler. When the refractive indices of both phases (inorganic and organic) mismatch the material is more opaque [46].

According to previous studies, composites based on BisGMA [42,47] are more translucent than those based on UDMA/TEGDMA, since the refractive index of BisGMA is closer to silica fillers index [48]. In our study, two of three composites with the highest RTP_{00} (AMN and PFP) contain BisGMA (Table 1). However, as manufacturers do not specify the exact percentage composition of the organic matrix, it is difficult to correlate the presence of a monomer to the translucency of the material.

Considering the influence of filler size, the particles whit a size below the wavelength of light will not absorb or scatter the light [46], so nanofilled composites, would be, in theory, more translucent than microhybrid composites. Furthermore, for a determined fill size, the higher the fill percentage, the lower the translucency [49]. Despite this, AMN, AXD, AXO, RGL, BGB VPG and PFP composites, with different filling percentages (i.e., 80% of AMN versus 58% of VPG; Table 1), presented a similar and significantly higher RTP_{00} compared to the other shades evaluated (Fig. 1).

Finally, light absorption is related to the nature and concentration of the pigments added to the composite to achieve a certain color. This would explain why composites with the same composition, percentage and type of filling (Renamel Gingafill's shade Light (RGL) and Dark (RGD)) showed significant differences in translucency. Previous studies concluded that the color of tooth-colored composite resins had a significant effect on their translucency; thus the more chromatic shades of dental composites are less translucent [39,50]. However, this effect was brand-dependent, as Beautiful II Gingiva's light and dark shades presented a similar RTP_{00}. Our study found differences in translucency between GCRBCs of the same shade of different brands and between different shades of the same brand, which were perceptible according to the translucency threshold values [35]. This effect should be considerer in the clinician choice of the restorative materials.

Optical properties of gingiva-colored composites were evaluated using Kubelka-Munk reflectance theory, which has been sufficiently demonstrated to be accurate [27]. Spectral reflectance of the gingiva-colored composites evaluated (Fig. 3) shows similar behavior to that described for healthy human gingiva in a previous study [51]. In addition, all shades of the gingiva-colored composites evaluated showed similar spectral behavior of T% and S-K coefficients.

The gingiva-colored composites tested showed a similar spectral behavior of the T% (Fig. 4b) and K coefficient (Fig. 4d) compared to that of the tooth-colored composites [25,26]. Thus, in terms of K, the spectral behavior decreased with wavelength, showing lower values for long wavelengths. At the same time, the T% increased with wavelength, due to the high value of the absorption coefficient compared to the value of the scattering coefficient for short wavelengths (Fig. 4c).

There are some differences between gingiva-colored composites and tooth-colored composites regarding the spectral behavior of S coefficient. Thus, in general, gingival composites showed a soft oscillatory behavior with peaks close to 420nm and 600nm (Fig. 4a), while dental composites showed a maximum value of S at approximately 450 nm and decreased slightly with increasing wavelength [26,45]. Thus, tooth-colored composite resins scatter mainly the short wavelengths of visible light, (blue light), being this spectral behavior of S and T% compatible with an opalescent effect [26,45].

Finally, it should be noted that although the spectral behavior of the S and K coefficients and T% is similar for all the GCRBCs evaluated, the values of these parameters presented statistically significant differences between shades, which would justify the differences found in relative translucency parameter values.

Translucency data of gingiva-colored composites found in the present study may significantly affect the clinician's choice of restorative material. When tooth defects associated with gingival recession were restored, a small amount of gingiva-colored composite may be adequate for opaque shades or slight changes in tooth color; but more material is required to mask pronounced discolorations, especially if more translucent gingiva-colored composites are used. In addition, differences in translucency between gingiva-colored composite resins of the same shade designation can lead to relevant differences in masking when a thin layer of material (in the range of thicknesses used clinically) is superimposed on darkened teeth [29,52].

5. Conclusions

1 There are perceptible differences in translucency between GCRBCs of the same shade of different commercial brands and between different shades of the same brand.
2 Despite the similitude of the optical properties between the evaluated GCRBCs, the values of the coefficients S, K and T% showed statistically significant differences between them, which would justify the translucency differences found.

CRediT authorship contribution statement

Cristina Lucena: Conceptualization, Resources, Writing – original draft, Supervision, Project administration. **Cristina Benavides-Reyes:** Investigation, Resources, Data curation. **Javier Ruiz-López:** Formal analysis, Investigation, Visualization. **Maria Tejada-Casado:** Formal analysis, Investigation, Data curation. **Rosa Pulgar:** Investigation, Resources. **María M. Pérez:** Methodology, Resources, Supervision, Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors report no conflict of interest.

Acknowledgments

The authors acknowledge funding support from the Spanish Ministry of Science, Innovation and Universities (PGC2018-101904-A-100) and from the i+D+I Government of Andalusia 2020, Spain (P20-00200).

References

[1] P.A. Heasman, M. Ritchie, A. Asuni, E. Gavillet, J.L. Simonsen, B. Nyvad, Gingival recession and root caries in the ageing population: a critical evaluation of treatments, J. Clin. Periodontol. 44 (2017) S178–S193, https://doi.org/10.1111/JCPE.12676.

[2] M.A. Wahbi, H.S. Al Sharief, H. Tayeb, A. Bokhari, Minimally invasive use of coloured composite resin in aesthetic restoration of periodontially involved teeth: Case report, Saudi Dent. J. 25 (2013) 83–89, https://doi.org/10.1016/J.SDENTJ.2013.02.001.

[3] G. Khashayar, Color Science in Dentistry, Vrije Universiteit Amsterdam, 2013.

[4] H. Günay, W. Geurtsen, A.K. Lührs, Conservative treatment of periodontal recessions with class v-defects using gingiva-shaded composite – a systematic treatment concept, Dent. Update. 38 (2017) 124–132, https://doi.org/10.12968/DENU.2011.38.2.124.

[5] S. Kamalakidis, G. Paniz, K.H. Kang, H. Hirayama, Nonsurgical management of soft tissue deficiencies for anterior single implant-supported restorations: A clinical report, J. Prosthet. Dent. 97 (2007) 1–5, https://doi.org/10.1016/J.PROSDENT.2006.12.005.

[6] M. Zalkind, N. Hochman, Alternative method of conservative esthetic treatment for gingival recession, J. Prosthet. Dent. 77 (1997) 561–563, https://doi.org/10.1016/S0022-3913(97)70094-5.

[7] P.C. Viana, Z. Kovacs, A. Correia, Purpose of esthetic risk assessment in prosthetic rehabilitations with gingiva-shade ceramics, Int. J. Esthet. Dent. 9 (2014) 480–489. https://www.ncbi.nlm.nih.gov/pubmed/25289383.

[8] P. Papaspyridakos, S. Amin, K. El-Rafie, H.P. Weber, Technique to Match Gingival Shade when Using Pink Ceramics for Anterior Fixed Implant Prostheses, J. Prosthodont. 27 (2018) 311–313, https://doi.org/10.1111/JOPR.12483.
[9] N. Sarmast, N. Angelov, R. Ghinea, J. Powers, R. Paravina, Color Compatibility of Gingival Shade Guides and Gingiva-Colored Dental Materials with Healthy Human Gingiva, Int. J. Periodontics Restorative Dent. 38 (2018) 397–403, https://doi.org/10.11607/prd.3430.
[10] A. Petropoulou, M. Dimitriadi, S. Zinelis, A. Sarafianou, G. Eliades, Surface Characteristics and Color Stability of Gingiva-Colored Resin Composites, Mater 13 (2020) 2540, https://doi.org/10.3390/MA13112540.
[11] H.S. An, J.M. Park, E.J. Park, Evaluation of shear bond strengths of gingiva-colored composite resin to porcelain, metal and zirconia substrates, J. Adv. Prosthodont. 3 (2011) 166–171, https://doi.org/10.4047/JAP.2011.3.3.166.
[12] E.M. Araújo, B.Tf. Silva, L.K. Siriani, A.D. Lago, M.R.L. Simionato, A.B. Matos, Effect of thermal and acid challenges on the surface properties of pink restorative materials, Am. J. Dent. 32 (2019) 159–164. http://www.ncbi.nlm.nih.gov/pubmed/31436934.
[13] A.A. Paryag, R.N. Rafeek, M.S. Mankee, J. Lowe, Exploring the versatility of gingiva-colored composite, Clin. Cosmet. Investig. Dent. 8 (2016) 63–69, https://doi.org/10.2147/CCIDE.S92727.
[14] A. Paryag, J. Lowe, R. Rafeek, Colored Gingiva Composite Used for the Rehabilitation of Gingiva Recessions and Non-Carious Cervical Lesions, Dent. J. 5 (2017) 33, https://doi.org/10.3390/DJ5040033.
[15] R.D. Paravina, R. Ghinea, L.J. Herrera, A.D. Bona, C. Igiel, M. Linninger, M. Sakai, H. Takahashi, E. Tashkandi, M. del Mar Perez, Color Difference Thresholds in Dentistry, J. Esthet. Restor. Dent. 27 (2015) S1–S9, https://doi.org/10.1111/jerd.12149.
[16] International Organization for Standardization, ISO/TR 28642:2016, Technical Report (E): Dentistry - Guidance on color measurements, ISO, Geneva, Switzerland, 2016.
[17] A.Della Bona, Color and Appearance in Dentistry, 1st ed., Springer, Cham, 2020 https://doi.org/10.1007/978-3-030-42626-2.
[18] P. Kubelka, New contributions to the optics of intensely light-scattering materials, J. Opt. Soc. Am. 38 (1948) 448–457, https://doi.org/10.1364/JOSA.38.000448.
[19] S.N. Thennadil, Relationship between the Kubelka-Munk scattering and radiative transfer coefficients, J. Opt. Soc. Am. A. 25 (2008) 1480–1485, https://doi.org/10.1364/JOSAA.25.001480.
[20] B.J. Brinkworth, Interpretation of the Kubelka-Munk Coefficients in Reflection Theory, Appl. Opt. 11 (1972) 1434–1435, https://doi.org/10.1364/AO.11.001434.
[21] J.C. Ragain, W.M. Johnston, Accuracy of Kubelka-Munk reflectance theory applied to human dentin and enamel, J. Dent. Res. 80 (2001) 449–452, https://doi.org/10.1177/00220345010800020901/SUPPL_FILE/449-00101_APX.PDF.
[22] O.E. Pecho, R. Ghinea, A.M. Ionescu, J.C. Cardona, A. Della Bona, M. Del Mar Pérez, Optical behavior of dental zirconia and dentin analyzed by Kubelka–Munk theory, Dent. Mater. 31 (2015) 60–67, https://doi.org/10.1016/J.DENTAL.2014.11.012.
[23] R. Pulgar, C. Lucena, C. Espinar, O.E. Pecho, J. Ruiz-López, A.Della Bona, M. M. Pérez, Optical and colorimetric evaluation of a multi-color polymer-infiltrated ceramic-network material, Dent. Mater. 35 (2019) e131–e139, https://doi.org/10.1016/j.dental.2019.03.010.L.M.
[24] B.C.dos Santos Schabbach, L.S. De Bortoli, M.C. Fredel, B. Henriques, Application of Kubelka-Munk model on the optical characterization of translucent dental zirconia, Mater. Chem. Phys. 258 (2021), 123994, https://doi.org/10.1016/J.MATCHEMPHYS.2020.123994.
[25] C. Lucena, J. Ruiz-López, R. Pulgar, A.Della Bona, M.M. Pérez, Optical behavior of one-shaded resin-based composites, Dent. Mater. 37 (2021) 840–848, https://doi.org/10.1016/j.dental.2021.02.011.
[26] O.E. Pecho, R. Ghinea, E.A.N. Do Amaral, J.C. Cardona, A. Della Bona, M.M. Pérez, Relevant optical properties for direct restorative materials, Dent. Mater. 32 (2016) e105–e112, https://doi.org/10.1016/j.dental.2016.02.008.
[27] S.S. Mikhail, S.S. Azer, W.M. Johnston, Accuracy of Kubelka-Munk reflectance theory for dental resin composite material, Dent. Mater. 28 (2012) 729–735, https://doi.org/10.1016/j.dental.2012.03.006.
[28] J.S. An, H.H. Son, S. Qadeer, S.W. Ju, J.S. Ahn, The influence of a continuous increase in thickness of opaque-shade composite resin on masking ability and translucency, Acta Odontol. Scand. 71 (2013) 120–129, https://doi.org/10.3109/00016357.2011.654250.
[29] K. Babina, A. Turkina, I. Sokhova, T. Budina, M. Makeeva, Comparative assessment of various composite materials and natural tooth tissue translucencies, Int. J. Esthet. Dent. 14 (2019) 406–419. https://pubmed.ncbi.nlm.nih.gov/31549106/.
[30] W.M. Johnston, M.H. Reisbick, Color and translucency changes during and after curing of esthetic restorative materials, Dent. Mater. 13 (1997) 89–97, https://doi.org/10.1016/S0109-5641(97)80017-6.
[31] W.M. Johnston, T. Ma, B.H. Kienle, Translucency parameter of colorants for maxillofacial prostheses, Int. J. Prosthodont. 8 (1995) 79–86. https://pubmed.ncbi.nlm.nih.gov/7710631/.
[32] W.M. Johnston, Review of Translucency Determinations and Applications to Dental Materials, J. Esthet. Restor. Dent. 26 (2014) 217–223, https://doi.org/10.1111/JERD.12112.
[33] D. Kürklü, S.S. Azer, B. Yilmaz, W.M. Johnston, Porcelain thickness and cement shade effects on the colour and translucency of porcelain veneering materials, J. Dent. 41 (2013) 1043–1050, https://doi.org/10.1016/J.JDENT.2013.08.017.
[34] M.N. Carney, W.M. Johnston, Appearance Differences Between Lots and Brands of Similar Shade Designations of Dental Composite Resins, J. Esthet. Restor. Dent. 29 (2017) E6–E14, https://doi.org/10.1111/JERD.12263.
[35] M. Salas, C. Lucena, L.J. Herrera, A. Yebra, A.Della Bona, M.M. Pérez, Translucency thresholds for dental materials, Dent. Mater. 34 (2018) 1168–1174, https://doi.org/10.1016/j.dental.2018.05.001.
[36] V. Kılıç, A. Gök, Effect of different polishing systems on the surface roughness of various bulk-fill and nano-filled resin-based composites: An atomic force microscopy and scanning electron microscopy study, Microsc. Res. Tech. 84 (2021) 2058–2067, https://doi.org/10.1002/JEMT.23761.
[37] M.R. Luo, G. Cui, B. Rigg, The development of the CIE 2000 colour-difference formula: CIEDE2000, Color Res. Appl. 26 (2001) 340–350, https://doi.org/10.1002/col.1049.
[38] The International Commission on Illumination, CIE 015:2018 Colorimetry, 4th edition, 2019. Vienna, Austria.
[39] H. Naeimi Akbar, K. Moharamzadeh, D.J. Wood, R. Van Noort, Relationship between color and translucency of multishaded dental composite resins, Int. J. Dent. 708032 (2012), https://doi.org/10.1155/2012/708032.
[40] T.A. Sulaiman, B. Rodgers, A.A. Suliman, W.M. Johnston, Color and translucency stability of contemporary resin-based restorative materials, J. Esthet. Restor. Dent. 33 (2020) 899–905, https://doi.org/10.1111/jerd.12640.
[41] B. Yu, Y.K. Lee, Influence of color parameters of resin composites on their translucency, Dent. Mater. 24 (2008) 1236–1242, https://doi.org/10.1016/J.DENTAL.2008.01.016.
[42] V. Miletic, N. Jakovljevic, D. Manojlovic, J. Marjanovic, A.A. Rosic, M. D. Dramićanin, Refractive indices of unfilled resin mixtures and cured composites related to color and translucency of conventional and low-shrinkage composites, J. Biomed. Mater. Res. - Part B Appl. Biomater. 105 (2017) 7–13, https://doi.org/10.1002/jbm.b.33523.
[43] N. Kolakarnprasert, M.R. Kaizer, D.K. Kim, Y. Zhang, New multi-layered zirconias: Composition, microstructure and translucency, Dent. Mater. 35 (2019) 797–806, https://doi.org/10.1016/J.DENTAL.2019.02.017.
[44] F.A. Sanal, H. Kilinc, Effect of shade and sintering temperature on the translucency parameter of a novel multi-layered monolithic zirconia in different thicknesses, J. Esthet. Restor. Dent. 32 (2020) 607–614, https://doi.org/10.1111/JERD.12598.
[45] M.M. Perez, C. Hita-Iglesias, R. Ghinea, A. Yebra, O.E. Pecho, A.M. Ionescu, A. Crespo, E. Hita, Optical properties of supra-nano spherical filled resin composites compared to nanofilled, nano-hybrid and micro-hybrid composites, Dent. Mater. J. 35 (2016) 353–359, https://doi.org/10.4012/dmj.2015-126.
[46] J.J. Kim, H.J. Moon, B.S. Lim, Y.K. Lee, S.H. Rhee, H.C. Yang, The effect of nanofiller on the opacity of experimental composites, J. Biomed. Mater. Res. Part B Appl. Biomater. 80B (2007) 332–338, https://doi.org/10.1002/JBM.B.30601.
[47] N. Azzopardi, K. Moharamzadeh, D.J. Wood, N. Martin, R. van Noort, Effect of resin matrix composition on the translucency of experimental dental composite resins, Dent. Mater. 25 (2009) 1564–1568, https://doi.org/10.1016/j.dental.2009.07.011.
[48] M. Ota, S. Ando, H. Endo, Y. Ogura, M. Miyazaki, Y. Hosoya, Influence of refractive index on optical parameters of experimental resin composites, Acta Odontol. Scand. 70 (2012) 362–367, https://doi.org/10.3109/00016357.2011.600724.
[49] Y.K. Lee, Influence of filler on the difference between the transmitted and reflected colors of experimental resin composites, Dent. Mater. 24 (2008) 1243–1247, https://doi.org/10.1016/j.dental.2008.01.014.
[50] B. Yu, Y.K. Lee, Differences in color, translucency and fluorescence between flowable and universal resin composites, J. Dent. 36 (2008) 840–846, https://doi.org/10.1016/J.JDENT.2008.06.003.
[51] D.K. Ho, R. Ghinea, L.J. Herrera, N. Angelov, R.D. Paravina, Color Range and Color Distribution of Healthy Human Gingiva: a Prospective Clinical Study, Sci. Reports 5 (2015) 18498, https://doi.org/10.1038/srep18498.
[52] M.M. Pérez, C. Benavides-Reyes, M. Tejada-Casado, J. Ruiz-López, C. Lucena, Does Backgrounds Color Influence the Appearance of Gingiva-Colored Resin-Based Composites? Mater 15 (2022) 3712, https://doi.org/10.3390/MA15103712.