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Original article

Effects of dyes used in photodynamic therapy on color stability of composite resins

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Abstract

Purpose: The aim of this study was to evaluate the effect of dyes used in photodynamic therapy (PDT) on color changes of resin-based composites (RBCs).
Methods: A total of 120 composite discs were made of microfilled, nanohybrid, and nanoceramic RBCs, and the CIE Lab system was used to assess initial colors with a spectrophotometer. Photosensitizers were used in accordance with the experimental design, as follows: MB (methylene blue), TB (toluidine blue), ICG (indocyanine green), and control (no dye). The samples were irradiated with a 940-nm diode laser. After irradiation, the photosensitizers were removed with distilled water (ΔE_1) and sodium hypochlorite (ΔE_2), and final colors were measured. Data were analyzed by the three-way ANOVA and Bonferroni tests ($\alpha = 0.05$).
Results: There was no statistically significant difference between the ICG and control groups; however, the TB and MB groups exhibited the strongest staining. The nanohybrid RBC exhibited the greatest color change, and there were no significant differences between the microhybrid and nanoceramic RBCs. After NaOCl irrigation, ΔE_2 values decreased to clinically acceptable values ($\Delta E_2 < 3.3$).
Conclusion: The intensity of staining of the RBCs differed according to the type of photosensitizer used and the content of the composite resin. The irrigant NaOCl was effective in removing discoloration.

Keywords: composite resin, discoloration, photodynamic therapy, photosensitizer dyes, sodium hypochlorite

Introduction

In dentistry, minimally invasive approaches are important for preserving and strengthening the tooth structure and increasing the longevity of restorations; therefore, conservative preparation of endodontic access cavities is recommended [1]. If crowned or restored teeth require endodontic treatment, the endodontic access cavity can be prepared without completely removing the restorations. Although restorations of crowned teeth must be renewed after root canal treatment, if the restoration is clinically satisfactory, the access cavity can be repaired with a composite resin. [2]. Composite restorations must sometimes be completely replaced by an invasive procedure. However, a considerable number of restorations can be preserved by minimally invasive repair methods. Data from retrospective studies suggest that composite repairs increase the longevity of restorations [3].

The practice of minimally invasive endodontics aims to treat pulp pathologies and apical periodontitis without causing excessive loss of dental hard tissues [4]. Recently developed systems and materials complement traditional chemo-mechanical procedures for intra-canal disinfection in endodontic treatments. In photodynamic therapy (PDT), photosensitizers sensitive to wavelength are produced by a low-power laser that binds microorganisms. A chemical reaction occurs when the laser is activated, and the free radicals and single oxygen formed by this reaction cause microbial cell death. The photosensitizers most commonly used in PDT are toluidine blue and methylene blue, which are non-cytotoxic and biocompatible at low concentrations. However, an undesirable effect of using these dyes in PDT is that they stain tooth structures, which results in an unattractive aesthetic appearance [5-7]. Fortunately, a 2.5% NaOCl solution used during cleaning and shaping of root canals prevented tooth stains caused by the photosensitizers used in PDT [8].

When endodontic treatment is needed for anterior teeth requiring clinically successful, aesthetic composite restoration, the restoration can be repaired by using a minimally invasive approach to prepare an endodontic access cavity, without completely removing the restoration [9,10]. In such cases, if PDT is preferred in canal irrigation, the degree of discoloration created by photosensitizing dyes in composite resins is important. Many studies have evaluated discoloration caused by PDT in dental tissue [5,8]; however, the effects of these photosensitizer dyes on staining of composite resins require clarification. To evaluate color change in resin-based composites (RBC) with different compositions, the authors simulated PDT application during endodontic treatment of anterior teeth with previous RBC restorations and investigated the effectiveness of NaOCl in preventing discoloration.

The hypotheses tested were (1) that discoloration induced by different photosensitizers would be similar for composite resins with different compositions and (2) that discoloration induced by different photosensitizers would be similar for distilled water and NaOCl irrigation solutions.

Materials and Methods

Specimen preparation

Sample size was calculated using G*Power software version 3.1.9, with 0.05 as the level of significance, an effect size of 0.4, and 0.95 as the study power. In accordance with the results of power analysis, 120 composite discs (8 mm in diameter; 5 mm in thickness) were prepared in a standardized mold by using the materials described in Table 1; the color code was A2 ($n = 40$ for each material). After the materials were placed in the molds, they were covered with a strip (Wilmington, DE, USA); a glass lamina (1 mm in thickness) was placed on top, pressed with a glass plate to provide a flat surface, and then removed after curing. In accordance with the manufacturer's instructions, a light-emitting diode device (Monitex Blue Lex GT-1200) was used in M1 mode at 1,200 mW/cm^2 power density and activated for 20 s in all cases at a distance of 1 mm. To complete polymerization, the samples were immersed in distilled water at 37°C for 24 h. They were then polished with a 4-step OptiDisc (Kerr Corp., Orange, CA, USA) containing aluminum oxide abrasive under a water spray (new discs were used for every 5 samples), with light pressure from coarse to fine grain. After each polishing step, the specimens were thoroughly rinsed with water for 10 s, to remove debris, and then air-dried for 5 s.

Initial color measurement

The initial color measurement of each specimen was made with a Vita EasyShade spectrophotometer (Vita Zahnfabrik, Bad Säckingen, Germany) calibrated before starting and again after measurement of every 10 samples. Composite discs were placed on a flat white surface inside of a black box in which the spectrophotometer was the only source of illumination. The spectrophotometer tip was always positioned perpendicular to the disc surface. All color measurements were made by the same operator, who was blinded to the composite group allocation. Color variation was established by using the coordinates L (lightness, 0-100), a (−a* = green,

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Table 1 Study materials and their composition

Composite	Composition	Manufacturer	Lot
Point 4 (microhybrid)	Poly (oxy-1,2-ethanediyl), α,α'-[(1- methylethylidene) di-4,1-phenylene] bis [ω-[(2- methyl-1-oxo-2-propen-1-yl) oxy] 2,2'-ethylenedioxydiethyl dimethacrylate 109-16-0 1-5%3-trimethoxysilylpropyl methacrylate 2530-85-0 1-5%7,7,9 (or 7,9,9)-trimethyl-4,13-dioxo-3,14- dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate 76% inorganic filler Bis-GMA, UDMA, TEGDMA	Kerr Corp., Orange, CA, USA	7401475
Harmonize (nanohybrid)	Poly (oxy-1,2-ethanediyl), α,α'-[(1- methylethylidene) di-4,1-phenylene]bis[ω-[(2- methyl-1-oxo-2-propen-1-yl) oxy]-3-trimethoxysilylpropyl methacrylate, 2,2'-ethylenedioxydiethyl dimethacrylate 81% inorganic filler BisGMA, BisEMA, TEGDMA	Kerr Corp.	7299635
ceram.x duo (nano-ceramic)	barium-alumino-borosilicate glass, methacrylate- glass, iron titanium and sulfosilicate pigments; glass filler size 1-1.5 µm, nanofiller size 10 nm, nanoparticle size 2.3 nm methacrylate modified polysiloxane 77-79% inorganic filler Bis-GMA, UDMA, TEGDMA	Dentsply Sirona Inc., York, PA, USA	1910001276

BisGMA, bisphenol A-glycidyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethandimethacrylate; BisEMA, bisphenol A diglycidyl methacrylate ethoxylated.

+a* = red), and b (−b* = blue, +b* = yellow) of the CIE L*a*b* scale. Calculations were made for ΔL, Δa, and Δb between the baseline. The formulas below were used for the ΔL, Δa, Δb, and ΔE values:

$\Delta L^* = L_2\text{-}L_1$

$\Delta a^* = a_2\text{-}a_1$

$\Delta b^* = b_2\text{-}b_1$

$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]½$

Application of photosensitizing dyes to composite resin cavities

Standard central cavities (4 mm diameter; 3 mm thickness) were prepared in order to imitate the endodontic access cavity into all the composite discs. Before applying PDT, 10 mL of distilled water was used, and the cavities were air-dried. The 40 discs corresponding to the different composite resins were randomly divided according to the dyes used in PDT (n = 10). In the control groups, the cavities were irrigated only with distilled water, and no photosensitizer dye was applied. The dyes (concentrations) used in the experimental groups were methylene blue (MB) (0.1 mg/ml) (Sisco Research Lab. Pvt. Ltd., Maharashtra, India), toluidine blue (TB) (1.0 mg/ml) (Sigma-Aldrich Corp., St. Louis, MO, USA), and indocyanine green (ICG) (5.0 mg/ml) (Pulsion Medical Systems SE, Feldkirchen, Germany).

After distilled water irrigation, the cavities were irrigated with 2.5 mL of photoactive dye, which was left in the cavities for 1 min. Without removing the dyes from the cavity, PDT was then applied with a 200-µm diameter tip using a 940-nm wavelength laser (continuous mode, 1 W, 1 min) (Epic, Biolase Technology, Irvine, CA, USA) source. The prepared specimens were then rinsed with 10 mL of distilled water and air-dried.

Final color measurement

After the discoloring process, the prepared specimens were rinsed with 10 mL of distilled water and air-dried. The composite specimens were again evaluated with the Vita Easyshade digital color-determination device, and calculations were made from ΔL_1, Δa_1, Δb_1, and ΔE_1, to represent irrigation with distilled water. After the dyes were removed from the cavities with distilled water, the cavities (except in the control group) were irrigated with NaOCl. After the composite cavities were washed with NaOCl, they were rinsed with water and dried, and the final color was measured immediately. The final measurements were recorded as ΔL_2, Δa_2, Δb_2, and ΔE_2. All measurements were made on the same surface of the composite discs.

Statistical analysis

Normality of each variable was evaluated with the Shapiro-Wilk test ($P > 0.05$). Mauchly's Test of Sphericity was used to evaluate homogeneity of variances and covariances ($P > 0.05$). The three-way ANOVA analysis and Bonferroni tests were used to evaluate the data and multiple comparisons. A P-value of ≤0.05 was considered to indicate statistical significance. The analyses were done with the SPSS 22 (SPSS Statistics 22, SPSS Inc., Somers, NY, USA) software package.

Results

The ΔL, Δa, Δb, and ΔE values of the study groups are shown in Tables 2, 3, 4, and 5, respectively.

RBC comparisons for ΔL, Δa, and Δb

A positive ΔL* indicates that the specimen became lighter, whereas a negative ΔL* indicates that the specimen became darker. After NaOCl, the MB, TB, and ICG groups of all RBCs exhibited negative ΔL_1 values, while the MB and TB groups of the Harmonized and Ceramic composites had negative ΔL_2 values. Although there was no significant difference for ΔL_1 and ΔL_2 measurements of the RBC control groups ($P > 0.05$), the ΔL_1 and ΔL_2 values of the MB, TB, and ICG groups showed significant differences ($P \leq 0.05$) (Table 2).

A negative Δa indicates a shift toward green, whereas a positive Δa indicates a shift toward red. When Δa_1 measurements for RBCs were compared, the MB, TB, and ICG groups significantly differed; the largest shift to green was in the Harmonize-MB group (Table 3). Δa_1 and Δa_2 values significantly differed in all RBC dye groups except the control group ($P \leq 0.05$).

The Δb_1 values significantly differed for the MB and TB groups for each composite resin, but the Harmonize specimens exhibited the largest shift to blue of all PDT dyes in the MB and TB groups ($P \leq 0.05$). A positive Δb indicates a shift toward yellow, while a negative Δb denotes a shift toward blue. A significant difference was observed between the Δb_1 and Δb_2 measurements for all MB and TB groups; however, among the RBCs, ICG did not significantly affect Δb_2 values ($P > 0.05$) (Table 4).

RBC comparisons for ΔE_1 and ΔE_2

No control or ICG group of any the tested materials exhibited a significant difference between ΔE_1 and ΔE_2 measurements ($P > 0.05$), whereas the ΔE_2 values for the MB and TB solutions were significantly lower than the ΔE_1 values ($P \leq 0.05$) (Table 5). The ΔE_1 values for MB and TB did not significantly differ but were significantly higher than those for ICG ($P \leq 0.05$) for all RBCs (Table 5). After NaOCl irrigation, discoloration was greatest for TB; only the Point 4 group specimens exhibited no significant difference between TB, MB, and ICG ($P > 0.05$) (Table 5). The control and ICG groups, and the ΔE_2-MB group, exhibited no significant difference in either measurement (ΔE_1 and ΔE_2) between the tested RBCs ($P > 0.05$), whereas MB and TB Harmonize specimens had significantly higher ΔE_1 values than did Point 4 and CeramX specimens ($P \leq 0.05$) (Table 5).

Discussion

Tissue loss may increase fracture tendency in endodontically treated anterior teeth. Because anterior teeth are subject to mechanical forces, such as strong shear force, their restorations require special attention [11]. Traditional endodontic access cavities aim to preserve healthy tooth structure by removing carious tissue and old restorations. With the emphasis on

Table 2 Distribution of ΔL values, by resin-based composite and solution

Composite	Solution	ΔL_1	ΔL_2
Point 4 (microhybrid)	Control	0.02 ± 0.28 Aax	0.33 ± 0.46 Aax
	MB	−1.26 ± 0.84 Aabx	1.13 ± 0.65 Aay
	TB	−2.29 ± 1.01 ABbx	0.52 ± 1.09 Aay
	ICG	−0.45 ± 0.67 Aax	1.30 ± 0.49 Aay
Harmonize (nanohybrid)	Control	−0.33 ± 0.30 Aax	0.59 ± 0.26 Aay
	MB	−2.46 ± 0.98 Bbx	−0.11 ± 0.89 Baby
	TB	−3.09 ± 0.92 Abx	−0.66 ± 0.44 Bby
	ICG	−0.6 ± 0.46 Aax	0.62 ± 0.49 ABay
ceram.x duo (nano-ceramic)	Control	−0.3 ± 1.16 Aax	0.62 ± 1.27 Aay
	MB	−1.6 ± 0.47 ABbx	−0.24 ± 0.54 Bay
	TB	−2.04 ± 1.44 Bbx	−0.32 ± 1.47 ABay
	ICG	−0.44 ± 1.33 Aax	0.09 ± 1.29 Bay

MB, methylene blue; TB, toluidine blue; ICG, indocyanine green. ΔL_1: distilled water irrigation groups, ΔL_2: NaOCl irrigation groups. ABC: different uppercase letters indicate a significant diffence between composite materials in a solution group. abc: different lowercase letters indicate a significant diffence between solutions in a composite material group. xy: different letters indicate a significant diffence between two measurements.

Table 3 Distribution of Δa values, by resin-based composite and solution

Composite	Solution	Δa_1	Δa_2
Point 4 (microhybrid)	Control	0.11 ± 0.17 Aax	0.15 ± 0.16 ABax
	MB	−1.97 ± 0.34 Abx	−0.16 ± 0.12 Aby
	TB	−1.10 ± 0.28 Acx	−0.04 ± 0.14 Aaby
	ICG	−0.74 ± 0.46 Acx	−0.17 ± 0.14 Aby
Harmonize (nanohybrid)	Control	0.10 ± 0.18 Aax	0.17 ± 0.13 Aax
	MB	−3.83 ± 0.58 Bbx	−0.73 ± 0.23 Bby
	TB	−3.04 ± 0.71 Bcx	−0.59 ± 0.29 Bby
	ICG	−0.92 ± 0.22 Adx	−0.33 ± 0.25 ABcy
ceram.x duo (nano-ceramic)	Control	−0.22 ± 0.16 Aax	−0.07 ± 0.13 Bax
	MB	−2.84 ± 1.00 Cbx	−0.67 ± 0.17 Bby
	TB	−1.93 ± 0.52 Ccx	−0.37 ± 0.34 Bcy
	ICG	−0.96 ± 0.27 Adx	−0.45 ± 0.26 Bbcy

Δa_1: distilled water irrigation groups, Δa_2: NaOCl irrigation groups. ABC: different uppercase letters indicate a significant diffence between composite materials in a solution group. abc: different lowercase letters indicate a significant diffence between solutions in a composite material group. xy: different letters indicate a significant diffence between two measurements.

Table 4 Distribution of Δb values, by resin-based composite and solution

Composite	Solution	Δb_1	Δb_2
Point 4 (microhybrid)	Control	0.05 ± 0.35 Aax	−0.70 ± 0.37 Aabx
	MB	−3.03 ± 0.59 Abx	−0.40 ± 0.32 Aay
	TB	−3.57 ± 1.09 Abx	−1.22 ± 0.35 Aby
	ICG	−0.65 ± 0.46 Aax	−0.35 ± 0.44 Aax
Harmonize (nanohybrid)	Control	0.44 ± 0.48 Aax	−0.58 ± 0.30 Aay
	MB	−4.00 ± 0.71 Bbx	−1.24 ± 0.38 Bby
	TB	−4.32 ± 0.84 Bbx	−2.23 ± 0.72 Bcy
	ICG	−0.29 ± 0.56 Aax	−0.53 ± 0.56 Aax
ceram.x duo (nano-ceramic)	Control	−0.08 ± 0.35 Aax	−0.74 ± 0.49 Aay
	MB	−2.43 ± 0.77 Abx	−1.00 ± 0.44 Bay
	TB	−3.30 ± 0.88 Acx	−1.76 ± 0.47 Bby
	ICG	−0.65 ± 0.58 Aax	−0.81 ± 0.51 Aax

Δb_1: distilled water irrigation groups, Δb_2: NaOCl irrigation groups. ABC: different uppercase letters indicate a significant diffence between composite materials in a solution group. abc: different lowercase letters indicate a significant diffence between solutions in a composite material group. xy: different letters indicate a significant diffence between two measurements.

Table 5 Distribution of ΔE values, by resin-based composite and solution

Composite	Solution	ΔE_1	ΔE_2
Point 4 (microhybrid)	Control	0.46 ± 0.10 Aax	0.89 ± 0.43 Aax
	MB	3.88 ± 0.84 Abx	1.27 ± 0.61 Aaby
	TB	4.49 ± 1.12 Abx	1.66 ± 0.48 Aby
	ICG	1.26 ± 0.64 Aax	1.43 ± 0.49 Aabx
Harmonize (nanohybrid)	Control	0.72 ± 0.34 Aax	0.89 ± 0.32 Aax
	MB	6.10 ± 1.10 Bbx	1.67 ± 0.44 Aby
	TB	6.14 ± 1.35 Bbx	2.42 ± 0.82 Bcy
	ICG	1.30 ± 0.36 Aax	1.10 ± 0.37 Aabx
ceram.x duo (nano-ceramic)	Control	0.87 ± 0.85 Aax	1.33 ± 0.96 Aax
	MB	4.09 ± 1.25 Abx	1.35 ± 0.38 Aay
	TB	4.52 ± 1.13 Abx	2.26 ± 0.72 ABby
	ICG	1.81 ± 0.52 Aax	1.41 ± 0.86 Aax

ΔE_1: distilled water irrigation groups, ΔE_2: NaOCl irrigation groups. ABC: different uppercase letters indicate a significant diffence between composite materials in a solution group. abc: different lowercase letters indicate a significant diffence between solutions in a composite material group. xy: different letters indicate a significant diffence between two measurements.

minimally invasive dentistry in recent years, ultra-conservative endodontic access cavities have been designed, with the aim of preserving healthy tooth structures [12,13]. Although the longevity of composite restorations is limited, partially defective or missing parts should be repaired by minimally invasive methods rather than by complete replacement of the restoration. Existing evidence shows that repaired restorations of permanent teeth have the same or better longevity than replacement restorations and that repairs are clinically satisfactory [3,14]. Therefore, this study was designed with the consideration that minimally invasive endodontic access cavities were opened in composite resin-restored anterior teeth, without completely replacing the restoration.

Many studies have reported that irrigation solutions, drugs, root-filling materials, and cements used in endodontic treatment can cause coronal coloration during and after treatment [15-18]. A disadvantage of PDT—a method for cleaning and disinfecting the root canal system—is that the dyes used stain tooth structures and result in an undesirable aesthetic appearance. A few studies investigated dental tissue discoloration induced by photosensitizers after PDT [5,19]. The present study evaluated color change in RBCs with different compositions by simulating PDT application during endodontic treatment for anterior teeth with previous RBC restorations, and investigated the effectiveness of NaOCl in preventing such discoloration. The first hypothesis was partially rejected because there were significant differences in discoloration between some of the composite resin groups and photosensitizer dyes. The second hypothesis was also partially rejected because distilled water and NaOCl irrigation solutions significantly affected discoloration induced by photosensitizer dyes in some test groups.

The CIE L* a*, and b* color system determines color according to 3 spatial coordinates, L*, a*, and b*, where L* represents the brightness (value) of a shade, a* represents the amount of red-green, and b* represents the amount of yellow-blue. This objective system, which can make sensitive, repeatable measurements and detect small color changes, was preferred for the current and previous color studies. Because most color studies used a threshold of ≥3.3 for clinically acceptable ΔE*, this value was used to evaluate color changes in the present study [20-23]. To assess the direction of color shifts for ΔE values greater than 3.3, ΔL*, Δa*, and Δb* were analyzed.

The staining potential of the PDT dyes used in this study (from least to most potential) can be expressed as ICG < MB < TB. ΔE values for ICG were generally similar to those of the control groups. ICG is a weak photosensitizer because the yields of the triplet state are lower than for other photosensitizers used in PDT [24]. MB and TB are photosensitizers derived from phenothiazine and thus stain the dental structure [19]. When ΔE_1 values of composite resins were examined, the MB and TB dyes caused color changes above the threshold value in all 3 composite types ($\Delta E_1^* \geq 3.3$), while the ICG groups exhibited no significant difference. Figueiredo et al., Costa et al., and Carvalho et al. found that MB and TB photosensitizers used in PDT promote tooth discoloration; their findings support the present results [5,8,19]. Previous studies used 2.5% NaOCl to remove MB and TB dyes in the protocol, to eliminate discoloration caused by photosensitizers on teeth after PDT, and achieved satisfactory results. Therefore, NaOCl was used in the present study to remove discoloration from composite resin. No control or ICG group of any of the tested materials showed a significant difference between ΔE_1 and ΔE_2 values ($P > 0.05$), whereas the ΔE_2 values for the MB and TB solutions were significantly lower than ΔE_1 ($P \leq 0.05$) (Table 5). This suggests that NaOCl performs better than distilled water in preventing discoloration caused by PDT dyes.

The present study assessed color stability of different types of composite resins exposed to the action of PDT dyes during endodontic treatment. The organic and inorganic structure of a resin composite and the characteristics of particles directly affect susceptibility to extrinsic staining [23,25,26]. The inorganic particle sizes and organic monomer contents of the Point 4 (microhybrid), Harmonize (nanohybrid), and ceram.x duo (nanoceramic) composite resins are different. When an ΔE of 3.3 is set as the acceptability threshold, TB and MB had greater staining potential than ICG in all materials; however, the coloring potential of ICG was not clear in previous studies [5,19].

Differences in ΔE_1 values may be related to resin content, monomer ratio, and particle types. Urethane dimethacrylate (UDMA) is a more stain-resistant hydrophobic monomer than BIS-GMA because of its low water absorption and solubility properties. As was suggested in other studies, the strong staining in the Harmonize groups can be attributed to the absence of UDMA [27-29]. Ceram.x duo, a nanoceramic composite resin ($\Delta E_1 = 4.52 \pm 1.13$), has well defined spherical superstructures, comprising submicron glass (77-79% filler content). In contrast, Point 4 ($\Delta E_1 = 4.49 \pm 1.12$) is a microhybrid composite resin with 76% filler content. When ΔE_1 values were compared for Ceram.x duo and Point 4 composite resins, no significant difference was observed in the TB, MB, or ICG group ($P > 0.05$), but they showed significant less staining than Harmonize specimens. The present results are consistent with past studies, which found that a microhybrid composite resin exhibited less coloration than a nanohybrid composite resin [29,30]. In addition to structural differences in composite resins, the molecular weights of the present TB (305.83 g/mol), MB (373.90 g/mol), and ICG (774.96 g/mol) dyes were different. The present authors believe that low-molecular-weight TB and MB have greater diffusion power than high-molecular-weight ICG and therefore cause greater color change in the composite structure [5,19].

Although low-wavelength light sources are generally used for PDT, there is no consensus in the literature about the optimal wavelength. Previous studies reported that a wavelength of 810 nm for ICG [31], a wavelength of 633 nm for TB, and a wavelength of 664 nm for MB were optimal values [32]. However, in dentin plaques infected with *Streptococcus mutans* Nagai et al. detected similar antibacterial activity for 650-nm laser MB and 940-nm laser MB groups [7].

Composite restorations are constantly exposed to temperature changes, pH cycles, and staining agents in the oral environment. The clinical difficulties caused by the oral environment are thus a limitation of this study. To limit tooth and restoration color change, future studies should attempt to determine the most appropriate and effective protocol for cavity disinfection, parameters of laser irradiation, and type, concentration, and exposure times of effective photosensitizers.

Despite the limitations of this study, the present findings indicate that the photosensitizers MB and TB, when used in PDT, caused significantly greater color change than ICG in RBCs. The microhybrid (Point 4) and nanoceramic (ceram.x duo) RBCs exhibited greater color stability than the nanohybrid (Harmonize) RBC. The effect of photosensitizer dyes on the color stability of RBCs depends on the type of dye and the composition of the resin composite used. A 2.5% NaOCl irrigation is recommended for removing color change caused by the photosensitizers used for PDT.

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Conflict of interest
None declared.

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