©Operative Dentistry, 2019, **44-4**, 396-404

The Use of Different Photoinitiator Systems in Photopolymerizing Resin Cements Through Ceramic Veneers

AJ Delgado • EM Castellanos • MAC Sinhoreti • DC Oliveira
N Abdulhameed • S Geraldeli • TA Sulaiman • J-F Roulet

Clinical Relevance

Amine-free cements may be an alternative selection for esthetic longevity of ceramic veneers. Resin cements containing only diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide might impair bond strength of the restoration in comparison to other photoinitiator systems and combinations.

SUMMARY

Objective: To evaluate the effect of different photoinitiator systems on photopolymerizing resin cements through ceramic veneers with different thickness on microshear bond strength (μSBS), flexural strength (FS), and ultimate tensile strength (UTS) and verify the light attenuation through these ceramic veneers.

Methods and Materials: Four photopolymerizing experimental resin cements were produced with the same resin matrix and associated with four different photoinitiator systems: camphorquinone (CQ), diphenyl(2,4,6-trimeth-

*Alex J Delgado, DDS, MS, Department of Restorative Dental Sciences, University of Florida, Gainesville, FL, USA

Edgar Mauricio Castellanos, DDS, MS, Department of Restorative Dental Sciences, University of Florida, Gainesville, FL, USA

Mário A Coelho Sinhoreti, DDS, MS, PhD, Department of Restorative Dentistry, Dental Materials Division, Piracicaba Dental School, University of Campinas, Piracicaba, SP, Brazil

Dayane CRS de Oliveira, DDS, MS, PhD, Department of Restorative Dentistry, Dental Materials Division, Piracicaba Dental School, University of Campinas, Piracicaba, SP, Brazil

Nader Abdulhameed, DDS, MS, PhD(c), Department of Restorative Dental Sciences, University of Florida, Gainesville, FL, USA

Saulo Geraldeli, DDS, PhD, Department of Restorative Dental Sciences, University of Florida, Gainesville, FL, USA

Taiseer Sulaiman, BDS, PhD, Department of Operative Dentistry, University of North Carolina, Chapel Hill, NC, USA

Jean-François Roulet, DMD, PhD, Department of Restorative Dental Sciences, University of Florida, Gainesville, FL, USA

*Corresponding author: 1395 Center Dr, D9-16C, Gainesville, FL 32610; e-mail: adelgado@dental.ufl.edu

DOI: http://doi.org/10.2341/17-263-L

ylbenzoyl)phosphine oxide (TPO), Ivocerin, and TPO + Ivocerin. Eighty disc-shaped ceramic veneers (IPS Empress Esthetic, Ivoclar Vivadent) were fabricated (10-mm diameter) in two different thicknesses: 0.7 and 1.5 mm. A previously characterized multiwave LED (Bluephase G2, Ivoclar Vivadent) was standardized for 40 seconds of photoactivation. Light transmittance through each ceramic veneer thickness (n=5) was measured using a spectrometer (USB 2000, Ocean Optics). The μSBS of each resin cement (n=15) to the ceramic veneer was evaluated using 0.5-mm cylinders with 0.7-mm diameters photoactivated through the different ceramic veneer thicknesses. Samples for FS and UTS tests were made either with or without ceramics veneers (0.7 and 1.5 mm) fixed to the light-curing tip. Data were submitted to two-way analysis of variance and the Tukey test (α=0.05).

Results: The multiwave LED emitted higher irradiance into the blue wavelength spectra than into the violet wavelength spectra (p=0.0001). Light transmittance through the ceramic veneers was reduced in a systematic manner based on thickness regardless of the wavelength spectra emitted from the multiwave LED (p=0.00037). The μSBS was reduced in a systematic manner based on thickness regardless of the photoinitiator system ($p<0.05$). However, resin cements with CQ and Ivocerin showed higher bond strength values in comparison to the resin cement with TPO regardless of the ceramic veneer thickness ($p<0.05$). The FS and UTS means decreased ($p<0.05$) with the interposition of 0.7- and 1.5-mm ceramic veneers for all resin cements. The resin cement containing only TPO showed the lowest FS and UTS means ($p<0.05$) for all ceramic veneers.

Conclusions: The thickness of the ceramic veneers reduced the irradiance of the multiwave LED in all wavelength spectra. Ivocerin alone or associated with TPO showed to be an effective alternative photoinitiator to substitute for CQ. The resin cement containing only TPO had lower bond strength values in comparison to resin cements with CQ, Ivocerin, and Ivocerin + TPO.

INTRODUCTION

Photoactivation is an important step to achieve clinical success when resin-based materials are used.[1] However, delivering the correct radiant exposure depends not only on adequate exposure time according to the irradiance of the light source but also on the compensatory irradiance lost.[2] The irradiance emitted from a dental curing source can be attenuated through a ceramic veneer for up to 80%.[3] This irradiance loss results from the veneer's crystalline structure, grain size, defects, intrinsic porosity, thickness, and shade, all of which interfere with the transmission of light.[4]

In addition, recent studies have shown that the shorter the wavelength of the light, the greater the light irradiance attenuation. This occurs not only because of natural light scattering through different materials but also because they possess shorter transmittance in depth than does blue wavelength (420-495 nm).[5,6] However, no information is available on the influence of violet light attenuation through ceramic veneers in the photopolymerizing of resin-based cements.

The photoinitiator most commonly used in resin-based dental materials is camphorquinone (CQ).[7] However, current photopolymerizing resin-based materials may contain other photoinitiator systems.[3] As a Norrish type II photoinitiator, CQ needs a coinitiator, such as tertiary amines, to react and create free radicals that are responsible for initiating the polymerization.[8] As highly reactive molecules, amines oxidize, producing a yellowing effect on resin-based material in the long term.[9]

On the other hand, Norrish type I photoinitiators do not require an amine-based coinitiator to generate free radicals.[8] These photoinitiator systems, called "amine-free," such as diphenyl(2,4,6-trimethylbenzoyl)phosphin oxide (TPO) and the new germanium-based photoinitiator, commercially known as Ivocerin, may substitute for CQ in dental resin-based materials. As a result, if used in resin-based materials, they would reduce the yellowing in the long term.[9]

Type I photoinitiators primarily absorb light in the violet spectrum,[8] and therefore the curing efficiency of "amine-free" resin-based cements might be affected regardless of whether a monowave or a multiwave LED is used. Thus, the aim of this study was to quantify the light attenuation through simulated ceramic veneers with different thicknesses and observe its effect on mechanical properties and bond strength of experimental "amine-free" photopolymerizing resin-based cements in contrast to CQ-amine photopolymerizing resin-based cements. The tested hypotheses were

Table 1: *Photoinitiator Systems Used in Photopolymerizing Resin-Based Cement Composition*

Photoinitiator (PI)	Coinitiator (CI)	PI:CI Concentration Ratio	Manufacturer
CQ	EDMAB	0.2wt%:0.2wt%	Sigma-Aldrich Inc (St Louis, MO, USA)
TPO	—	0.4wt%:0wt%	Sigma-Aldrich
Ivocerin	—	0.1wt%:0wt%	Ivoclar Vivadent (Schaan, Liechtenstein)
Ivocerin+TPO	—	0.1wt%:0.2wt%:0wt%	

Abbreviations: CQ, camphorquinone; EDMAB, ethyl 4-(dimethylamino)benzoate; TPO, diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide.

the following: 1) light attenuation through simulated ceramic veneers with different thicknesses is different, 2) thickness of the ceramic would directly influence mechanical properties and ceramic bond strength, and 3) "amine-free" resin-based cements with type I photoinitiators have similar mechanical properties and ceramic bond strength as CQ-amine resin-based cements.

METHODS AND MATERIALS

Resin-Based Cement Preparation

Four experimental photopolymerizing resin-based cement formulations were tested. The resin blend for the formulations consisted of a combination of 20% by weight of bisphenol glycidyl methacrylate, 10% by weight of urethane dimethacrylate, and 10% by weight of triethylene glycol dimethacrylate (Sigma-Aldrich Inc, St Louis, MO, USA). Different photoinitiators were added to these resin blends, as shown in Table 1. Hereafter, each resin blend was loaded with 60% by weight of silanated filler (10wt% silica with 0.05-μm particle size [Aerosil OX50, Nippon Aerosil Co Ltd, Tokyo, Japan]) and 50wt% $BaBSiO_2$ glass with 0.7-μm particle size (Esstech Inc, Essington, PA, USA). All components were mixed using a centrifugal mixing device (SpeedMixer, DAC 150.1 FVZ-K, Hauschild Engineering, Hamm, Germany).

Ceramic Specimen Preparation

Eighty disc-shaped specimens (IPS Empress Esthetic ceramic system, Ivoclar Vivadent, Schaan, Liechtenstein) shade LT A2 with a 10-mm diameter were prepared following the manufacturer's instructions. The specimens were divided into two groups depending on thickness (0.7 and 1.5 mm) and were further divided into four groups depending on which photopolymerizing resin-based cement was used (n=10).

Light Attenuation Measurement

Bluephase G2 polymerizing light (Ivoclar Vivadent) with a standardized tip (10-mm diameter) was used in this study. The output power (mW) was measured with a calibrated power meter (Ophir Optronics, Jerusalem, Israel). The light irradiance (mW/cm^2) was calculated by dividing the output power by the area of the light tip. The spectral distribution was obtained by using a precalibrated spectrometer (USB2000, Ocean Optics, Dunedin, FL, USA), and the spectral distribution data were integrated using Origin 6.0 software (OriginLab, Northampton, MA, USA). All light attenuation analyses were performed using five ceramic discs of each thickness positioned right above the polymerizing light tip, and light transmittance was measured through the different ceramic disk thicknesses. For the control group, this procedure was performed without a ceramic disk, with the cement layer positioned right above the polymerizing light tip.

Absorption Spectrophotometric Analyses

A spectrophotometric analysis was performed to evaluate the absorption of each photoinitiator in the wavelength range of 360-540 nm using a UV-Vis spectrophotometer (U-2450, Hitachi High-Technologies, Tokyo, Japan). Each photoinitiator was diluted in 1 mL of triethylene glycol dimethacrylate (Sigma-Aldrich). The spectra were collected using a quartz cell with a path length of 1 cm.

Mechanical Properties Testing

Flexural Strength—Ten bar-shaped specimens (10-mm long×2-mm wide×1-mm thick)[10] of each experimental resin-based cement were made from rubber molds and photopolymerized for 40 seconds through the ceramic discs (0.7- or 1.5-mm thickness) fixed onto the output region of the polymerizing light tip. For that, a polyester strip was placed in between the mold and the ceramic disc fixed onto the light tip. After polymerization, the specimens were removed from the molds and stored dry in lightproof containers at 37°C for 24 hours. The three-point bending test was performed in a universal testing machine (Instron, Canton, OH, USA; span between supports=5 mm) at a crosshead speed of 0.5-mm/min. Load application was performed on the same side of the specimen that was

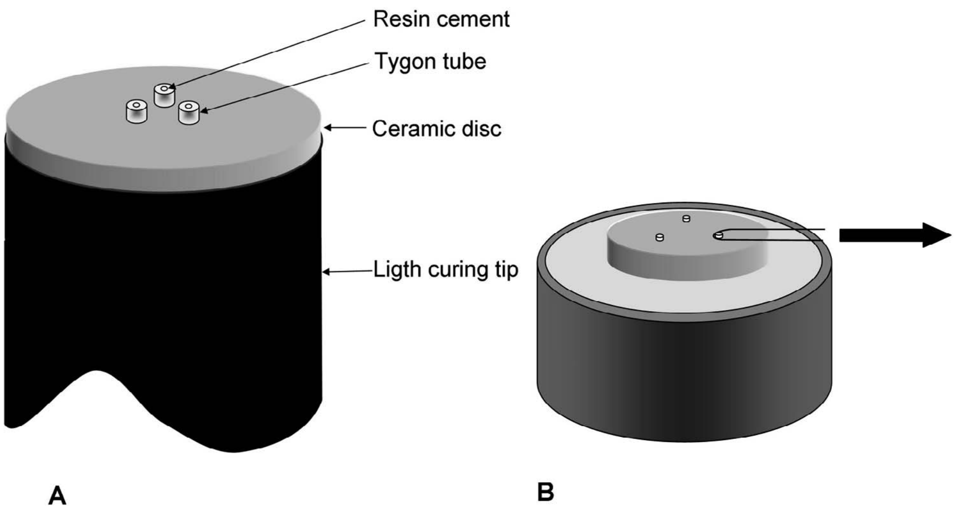

Figure 1. *(A): Schematic illustration of specimen's preparation and photoactivation through ceramic disc. (B): Steel wire looped around the resin cement cylinder for the microshear bond strength (μSBS) test.*

irradiated with the LCU. The maximum fracture load for the specimens was recorded and the flexural strength (FS) calculated using the following equation: $FS = 3FL/(2bh^2)$, where F is the maximum load (N) exerted on the specimens, L is the distance (mm) between the supports, b is the width (mm) of the specimens measured immediately prior to the test, and h is the height (mm) of the specimens measured immediately before the test.

Ultimate Tensile Strength—Specimens of each experimental resin-based cement (n=10) were prepared using 1-mm-thick silicon molds with a 10 × 4-mm hourglass-shape, and a constriction zone of 1.5 × 1-mm (cross-sectional area of 1.5 mm^2) - Odeme Dental Research, Luzerna, Brazil). They were photopolymerized and stored as previously mentioned. Specimens were fitted in a test jig device and subjected to tensile strength testing in a mechanical testing machine OM100 (Odeme Dental Research) at 0.75 mm/min. The UTS was calculated in MPa using the formula CS = F/A, where F is the tensile strength (N) and A is the sample transversal cross-sectional area (mm^2).

Microshear Bond Strength—The internal surface of the ceramic discs for each group (n=10) was etched with 9% hydrofluoric acid gel (Ultradent Products, South Jordan, UT, USA) at room temperature (25°C±1°C) for 20 seconds and rinsed with air-water spray for 20 seconds. A silane coupling solution (Monobond-S, Ivoclar Vivadent) was placed on the etched surface of the ceramic discs, rubbed for 15 seconds with a microbrush, and allowed to air-dry for one minute. A thin layer of a hydrophobic resin (OptiBond FL adhesive, Kerr, Orange, CA, USA) was applied, and three translucent Tygon tubings (0.7-mm internal diameter×0.5-mm height) were positioned on the ceramic disc surface. The hydrophobic resin was photopolymerized and the respective resin-based cement carefully inserted with a snap-fit syringe and 20-gauge needle (Centrix Corp, Shelton, CT, USA) into the Tygon tube lumen. After filling all three Tygon tubing molds, the resin-based cement was photopolymerized for 40 seconds (Figure 1A).

The specimens were stored dry in lightproof containers for 24 hours at 37°C, and the Tygon tubes were removed using a scalpel blade to expose the resin-based cement cylinders. A stereomicroscope (SMZ-1B, Nikon, Tokyo, Japan) was used with 30× magnification to confirm that none of the cylinders had defects or flaws at the ceramic/adhesive/resin cement peripheral bonding area. The ceramic discs were bonded to polyvinyl chloride tubes filled with acrylic resin using cyanoacrylate glue (Super Bonder, Loctite, Düsseldorf, Germany). The polyvinyl chloride tube was positioned in a microshear bond strength (μSBS) device that was assembled to a mechanical testing machine (OM100, Odeme Dental Research). A thin stainless-steel wire (0.2 mm in diameter) was looped around the base of each cylinder and aligned with the bonding interface (Figure 1B). Each cylinder was subjected to a crosshead speed of 0.75 mm/min until failure. The mean of the three cylinders bonded to each ceramic disc was used as the mean of that specimen for statistical analysis. The debonded interfaces were examined under a stereomicroscope (SMZ-1B, Nikon) at 30× magnification and classified as adhesive, cohesive within the ceramic, cohesive within the resin cement, and mixed (involving ceramic/adhesive/resin cement).

Table 2: *Light Irradiance (mW/cm[2]) Through Ceramic Discs With Different Thicknesses[a]*

Wavelength	Bluephase G2	0.7 mm	1.5 mm
380-420 nm (violet)	357±1.32 A	177±4.56 B	90±3.54 C
420-495 nm (blue)	1080±3.87 A	604±7.28 B	395±6.61 C
Total	1438	781	486

[a] *Means followed by same letter in a row are not statistically different at the 5% level by the Tukey test.*

Statistical Analysis

The irradiance data for each wavelength range were analyzed by one-way analysis of variance (ANOVA) and the Tukey test for pairwise comparisons. The factor considered was ceramic thickness in three levels (0.7 mm, 1.5 mm, and control). The FS, UTS, and μSBS data were analyzed by two-way ANOVA and the Tukey test for multiple comparisons. The two factors analyzed were the photoinitiator in four levels (CQ, TPO, Ivocerin, and Ivocerin+TPO) and the ceramic thickness in three levels (0.7 mm, 1.5 mm, and control) considering the three tests, except for the μSBS test, where the ceramic thickness factor was analyzed in two levels (0.7 and 1.5 mm). Power analysis was conducted to determine sample size for each experiment to provide a power of at least 0.8 at a significance level of 0.5 ("β=0.2).

RESULTS

Light Attenuation Measurement

The one-way ANOVA showed significant effect of ceramic thickness on the irradiance ($p<0.01$). The results for the Tukey test and the means of light irradiance transmitting through the ceramic discs are described in Table 2. A statistical reduction in the irradiance within the blue and violet spectra can be observed with the interposition of ceramic discs with a thickness of 0.7 or 1.5 mm ($p<0.05$) (Table 2). The irradiance of the multiwave LED light-polymerizing unit was reduced by 46% when a 0.7-mm-thick ceramic disc was interposed and by ±66% with a 1.5-mm-thick ceramic disc. In addition, the multiwave LED emitted 357 (±1.32) mW/cm^2 into the violet spectrum (±25%) and 1080 (±3.87) mW/cm^2 into the blue spectrum (±75%). The irradiance into the violet spectrum was reduced by 50%-75%, while the irradiance into the blue spectrum was reduced by 44%-66%.

Absorption Spectrophotometric Analyses

Figure 2 illustrates the spectral irradiance for the multiwave LED compared to the absorbance of each photoinitiator plotted against wavelength. The absorption peak of CQ is approximately at 470 nm, and most of the absorption is within the 420-495-nm range (blue spectrum). The multiwave LED shows two peaks, one within the blue region (460 nm) and one within the violet (408 nm), with the former mainly overlapping the CQ absorbance. The absorption peak of the TPO is near the UV-A region and extends to the violet spectrum range (380-420 nm), thus overlapping with the violet light spectrum emission peak of the multiwave LED at 400 nm. The absorption peak of Ivocerin is set in the violet spectrum (380-420 nm) and slightly extends to the blue spectrum range (420-455 nm), thus overlapping mostly with the violet light spectrum emission peak at 410 nm and part with the blue spectrum emission peak at 445 nm.

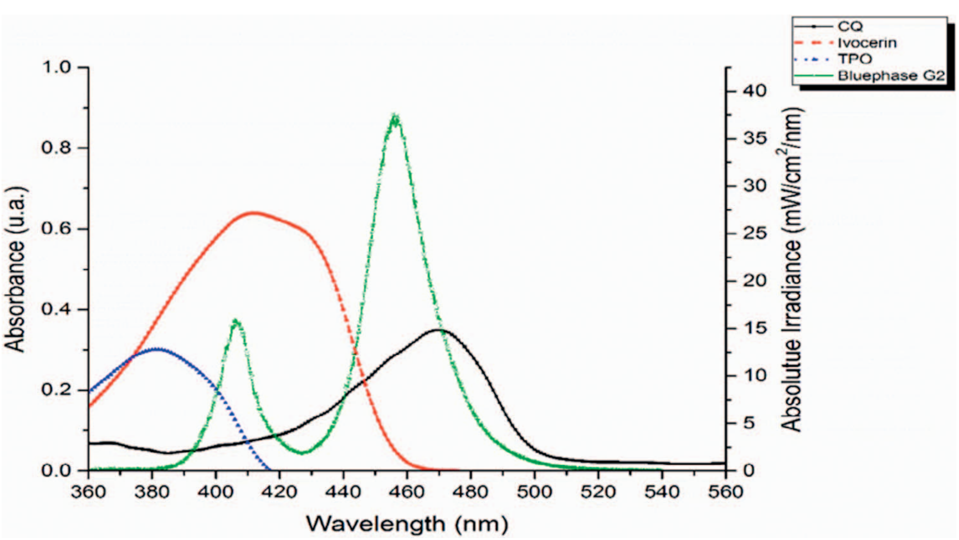

Figure 2. *Absorbance of camphorquinone (CQ), diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide (TPO), and Ivocerin into 360-560-nm spectra and spectral irradiance of the multiwave LED light-curing unit Bluephase G2.*

Table 3: *Flexural Strength and Ultimate Tensile Strength (MPa) of Experimental Resin-Based Cements Containing Different Photoinitiator Systems*[a]

Material	Flexural Strength			Ultimate Tensile Strength		
	Control	0.7 mm	1.5 mm	Control	0.7 mm	1.5 mm
CQ	120.41±9.21 aA	105.25±8.97 aB	88.94±4.84 aC	32.41±2.97 aA	28.29±2.54 aB	21.56±2.70 aC
TPO	113.01±8.26 bA	93.81±5.81 bB	69.72±5.81 bC	28.07±2.02 bA	22.35±2.42 bB	14.89±3.60 bC
Ivocerin	119.93±8.10 abA	108.74±10.06 aB	88.63±6.25 aC	31.42±2.91 abA	29.11±3.28 aB	21.05±2.86 aC
Ivocerin+TPO	122.26±10.60 aA	107.51±9.35 aB	90.55±6.55 aC	33.01±3.17 aA	29.81±2.94 aB	19.97±2.64 aC

Abbreviations: CQ, camphorquinone; TPO, diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide.
[a] *For each property, means followed by same small letter in the same column and capital letter in a row are not statistically different at the 5% level by the Tukey test.*

Mechanical Properties

The two-way ANOVA for the FS test demonstrated that photoinitiator ($p<0.00001$) and ceramic thickness ($p<0.00001$) factors were significant, as was the interaction between these factors ($p=0.02143$). For the UTS test, two-way ANOVA showed that the photoinitiator ($p<0.00001$) and ceramic thickness ($p<0.00001$) factors were significant. The interaction between these factors was also significant ($p=0.03666$). Table 3 shows the means and standard deviations for FS and UTS of all the resin-based cements that were photopolymerized through ceramic discs. Ceramic discs with thicknesses of 0.7 and 1.5 mm reduced the FS and UTS for all resin-based cements ($p<0.05$). The resin-based cement containing only TPO as the photoinitiator system showed the lowest FS and UTS means ($p<0.05$) regardless of the ceramic disc thickness used (0.7 or 1.5 mm).

Table 4 shows the μSBS means and standard deviations for all resin-based cements photopolymerized through ceramic discs with different thicknesses. The two-way ANOVA demonstrated that the photoinitiator ($p<0.00001$) and ceramic thickness ($p<0.00001$) factors were significant, as was the interaction between these factors ($p=0.02801$). The thickness of the ceramic discs reduced the μSBS means regardless of the photoinitiator system used ($p<0.05$). However, the resin-based cement with the TPO system showed lower bond strength values in comparison to the resin-based cements with other photoinitiator systems when photopolymerized through ceramic discs of both 0.7- and 1.5-mm thicknesses ($p<0.05$). The differences in μSBS between resin-based cements with Ivocerin and Ivocerin + TPO ($p>0.05$) were not significant.

Table 4: *Microshear Bond Strength Means (MPa) for Experimental Resin-Based Cements Containing Different Photoinitiators*[a]

Material	Thickness	
	0.7 mm	1.5 mm
CQ	30.10±2.44 aA	23.35±2.62 aB
TPO	25.46±2.49 bA	17.54±3.12 bB
Ivocerin	29.33±2.91 aA	21.35±2.77 abB
Ivocerin+TPO	29.95±3.06 aA	21.88±3.13 abB

Abbreviations: CQ, camphorquinone; TPO, diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide.
[a] *Means followed by same small letter in the same column and capital letter in a row are not statistically different at the 5% level by the Tukey test.*

Adhesive failures were dominant for all groups with 0.7-mm-thick ceramic discs, except for the Ivocerin + TPO group, which showed similar percentages of adhesive and mixed failures (Figure 3). No cohesive failures within the ceramic substrate were verified. Cohesive failures within resin-based cement were observed only in the TPO and Ivocerin groups. For 1.5-mm thickness, adhesive failures were dominant in all groups. No cohesive failures within the ceramic were verified.

DISCUSSION

The first tested hypothesis that light attenuation through ceramic veneers with different thicknesses would be different was accepted. For the control group, photoactivation was performed without a ceramic disk, with the cement layer positioned right above the polymerizing light. Despite being closer to the light exiting window would possibly change the irradiation as compared to a 0.7- or 1.5-mm distance, the multiwave polymerizing light reached the same irradiance at a 0-mm distance as at a 1.5-mm distance. Then the only influence on irradiance attenuation would be the interposing of the ceramic disk. As observed in the Results section, light transmittance through the ceramic veneers was reduced in a systematic manner based on thickness regardless of the resin-based cement used. Consequently, the second tested hypothesis—that the thickness of ceramic would directly influence the mechanical properties and ceramic bond strength—

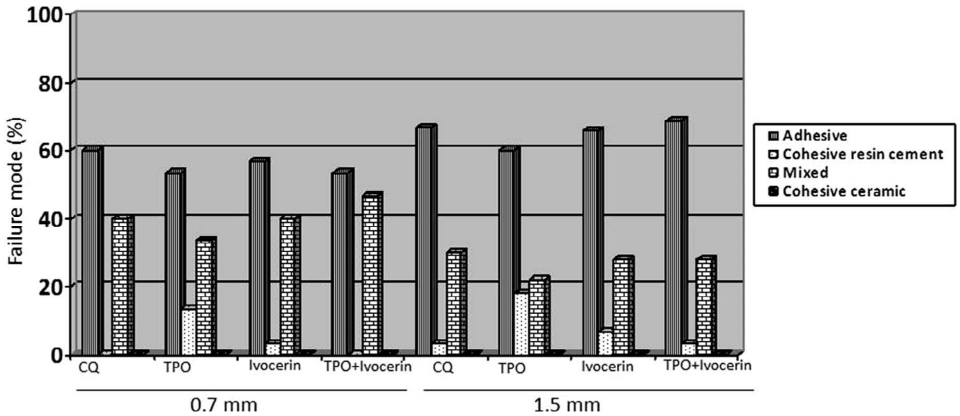

Figure 3. *Percentage failure mode for the debonded specimens.*

was accepted. As observed in the Results section, mechanical properties and ceramic bond strength were also reduced in a systematic manner based on the thickness of the ceramic veneer.

However, it is important to note that despite the high irradiance of the multiwave LED, only 25% of its light was emitted in the violet spectrum, while the other 75% was emitted in the blue spectrum. In addition, the lowest irradiance was emitted in the violet spectrum, and the attenuation of the violet spectrum was higher than the blue spectrum in depth (Table 2). Moreover, the results showed that type I photoinitiators absorbed visible light within the violet spectrum, while CQ absorbed it only into the blue spectrum, as supported by other studies.[5,8,9] TPO absorbed visible light into the violet spectrum, and Ivocerin absorbed it in both the violet and the blue spectrum. Thus, the mechanical properties and ceramic bond strength of resin cements containing type I photoinitiators could be affected.

The results showed that amine-free resin-based cement containing only TPO presented the lowest flexural and ceramic bond strengths. However, the amine-free resin-based cement containing Ivocerin or the combination of Ivocerin and TPO presented similar FS and ceramic μSBS compared to conventional resin-based cement containing CQ-amine (Tables 3 and 4). Previous studies in conventional and bulk-fill resin-based composite materials have demonstrated the potential for combining photoinitiators .[5,11] The data of this study confirm this potential with resin-based cements as well. Thus, the third tested hypothesis—that "amine-free" resin-based cements with type I photoinitiators would have similar mechanical properties and ceramic bond strength as CQ-amine resin cements—was partially accepted, as resin-based cements with TPO showed lower mechanical properties and bond strength values to ceramic veneer than did the other cements; however, the other "amine-free" resin cements showed as high mechanical properties and bond strength values as the CQ-amine resin cement.

It is noteworthy that the difference in attenuation of the different wavelength spectra in which each system with different absorbed photoinitiator directly influenced its luting performance according to the thickness of the ceramic veneer. However, it is important to comment that type I photoinitiators can either maintain or reduce the properties of the material, as shown in the literature.[5,9,11-20.] Therefore, it is important to take into account the use of resin-based cements containing these alternative photoinitiators for different clinical scenarios. As for the esthetic benefits that these alternative photoinitiators might produce on luting ceramic veneers, their clinical indications may be limited for thick ceramic restorations.

The irradiance was systematically attenuated based on thickness of the simulated ceramic veneer interposed between the resin-based cement and the multiwave LED light tip, mainly for violet light, resulting in 177 mW/cm^2 for ceramics with 0.7-mm thickness and 90 mW/cm^2 for 1.5-mm thickness (Table 2). These findings are supported by other studies.[3,4,21] However, the higher emittance of the light in the blue spectrum compared to the emittance of the light in the violet spectrum appeared to benefit Ivocerin in contrast to TPO, which absorbed light only in the violet spectrum. It can be observed that flexural and bond strengths were also affected according to the thickness of the ceramic during photopolymerization. The molar extinction coefficient of TPO molecules is much greater than CQ molecules,[22] meaning that its photon absorption efficiency is higher; thus, the excitation of the TPO molecules occurs faster than in CQ molecules and accelerates the kinetics of conversion. Moreover, TPO, as a Norrish type I photoinitiator, suffers a direct cleavage in the C-P bond, generating two radicals—an acyl and a phosphonyl radical—that immediately initiate the polymerization process,[8] while CQ, as a Norrish type II photoinitiator, requires a coinitiator to react and generate free radicals that can initiate the polymerization process.[8] This means that regardless of whether CQ is excited, it depends on its proximity to a coinitiator so that the reaction can occur. Nonetheless, amine-free resin-based cements containing TPO alone always showed lower flexural and bond strengths compared to the conventional resin-based cements containing CQ-amine.

An increase in thickness of the ceramic exhibits lower percentages of mixed failures and higher percentages of cohesive failures, independently of the photoinitiator system (Figure 3). One possible explanation is because the thicker the ceramic, the higher the light attenuation through the resin-cement layer and thus the lower the light energy for photopolymerization of this layer, causing a reduction in physical properties. This explains the lower bonding results when the resin-based cements were photoactivated with the 1.5-mm simulated ceramic veneer compared to the 0.7-mm veneer. In addition, the resin-based cement with TPO presented the highest percentage of cohesive resin-based cement failures compared to the resin-based cements with other photoinitiator systems. It is almost certain that violet light had higher attenuation, causing the decrease of light transmittance through the resin cement, and thus TPO initiators did not have sufficient light energy to form polymers with the same physical properties as the other photoinitiators, explaining the lower bonding results.

It is also important to mention that adhesive failures were the most dominant type of failure in this study, and these failures occurred on the interface between the adhesive and the ceramic. This type of failure is the most dominant type of failure using μSBS tests, and it basically depends on the adhesive system. Because of that, the same adhesive system was used for all groups tested in this study. Still, the cohesive failures in the resin cement are the second most dominant type of failure. This failure highly depends on the physical properties of the resin cements. And, as observed in this study, the type of photoinitiator was capable of influencing the resin cement's properties as well as the type of bond strength failure. However, further studies should also evaluate the influence of photoinitiator system of the adhesive system on these properties.

In conclusion, the use of type I photoinitiators (like Ivocerin and TPO) as an alternative to CQ-amine systems could be a clear strategy to reduce initial yellowing of materials. However, clinical limitations should be established in order not to extrapolate their clinical indications and impair longevity of ceramic veneers on behalf of esthetics.

CONCLUSIONS

The thickness of the ceramic veneers reduced the irradiance of the multiwave LED in all wavelength spectra. Ivocerin alone or associated with TPO was shown to be an effective alternative photoinitiator to substitute for CQ. Resin-based cements containing only TPO had lower bond strength values in comparison to resin-based cements with CQ, Ivocerin, and Ivocerin + TPO.

Acknowledgements

We would like to acknowledge Ivoclar Vivadent for the kind donation of the Ivocerin, which was tested in this study. DO is a postdoctoral researcher at FAPESP (grant #2016/05823-3).

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 18 June 2018)

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