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Influence of Mono- and Multiwave Light-curing Units on the Microhardness and Degree of Conversion of Light-cured Resin Cements

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Clinical Relevance

Light-cured resin cements must be light-cured with a good-quality light-curing unit over the entire length of the indirect restoration. However, the particular type of light-curing unit used (mono- or multiwave) does not affect the performance of these cements.

SUMMARY

Objectives: This study evaluated the Knoop hardness (KH, N/mm²) and degree of conversion (DC, %) on the margins of light-cured resin cements with different photoinitiators using a single light-curing unit (LCU) with two heads (mono- and multiwave).

Methods and Materials: Three types of resin cements were used with different photoinitiators: Megalink Esthetic (Odontomega, São Paulo, Brazil) with a camphorquinone photoinitiator; Allcem Veneer (FGM, Joinville, Brazil) with the Advanced Polymerization system (APS), and Variolink Esthetic LC (Ivoclar Vivadent, Schaan, Liechtenstein). Thirty samples were collected and divided into six groups (n=5 each). The resin cement

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samples were made into the shape of a maxillary right central incisor and photoactivated under a 0.5-mm-thick ceramic sheet. A single LCU (Radii Xpert, SDI) with two heads (mono- and multiwave) was used. The tip of the LCU was positioned at the center of the sample in a standardized manner. Raman spectroscopy was performed to evaluate the DC, and KH was evaluated through the Knoop microhardness test. Five regions were evaluated: cervical, mesial, buccal (center), distal, and incisal.

Results: There was a significant difference in the DC only for the type of cement ($p<0.001$), indicating that the cement with the APS photoinitiator presented excellent results. There were significant differences in the type of cement ($p<0.001$), type of light ($p<0.001$), region ($p<0.001$), and the interaction between the type of cement and type of light ($p<0.001$). The resin cement with the APS photoinitiator cured with monowave light showed the highest KH values. The beam profiles of all groups, with and without the interposition of ceramic and resin cement, were examined by light transmission.

Conclusions: The cement with the APS photoinitiator presented the best results with respect to the DC and KH. In comparison with mono- and multiwaves, the LCU may not be a determining factor for the properties of light-cured resin cements. The buccal region showed the best results for DC and KH, indicating the need for a greater amount of light-curing at the cementation margins.

INTRODUCTION

Cementation is essential in determining the final success and longevity of ceramic restorations.[1,2] The main cause of failure of ceramic veneers is related to the cementing process.[3] The adequate polymerization of the resin cement selected for cementation can influence stress propagation at restorations and interfaces.[4]

Light-cured resin cements are considered to be better materials for the cementation of ceramic veneers.[5] Controlled working time, easy removal of excess material, low technical sensitivity to the operator, small film thickness, good physical properties, low solubility, and good adhesion are some of the characteristics supporting the selection of light-cured resin cements.[6,7] The light-curing process is essential for the proper polymerization of this class of resin cement, influencing the long-term clinical performance of ceramic veneer restorations.[4] The exposure time and delivered energy must be sufficient to excite the photoinitiator system present in the resin cement to generate free radicals and thus initiate the polymerization process.[8] A deficient polymerization process can result in premature clinical failure due to marginal defects, recurrent caries, or even fracture of the ceramic restorations.[9]

Camphorquinone (CQ) is the most frequently used photoinitiator available on the market; its yellowish color contributes to the pigmentation of the material, compromising esthetics.[10] The search for yellow-free resin cement has led manufacturers to develop resin cement with different photoinitiators, which replace or reduce the use of CQ.[11] Photoinitiators such as trimethylphosphinic oxide (TPO), Ivocerin (benzoyl germanium), phenyl propanedione, and advanced polymerization system (APS) were introduced to the market.[12] The APS system, according to the manufacturer, uses a combination of several initiators, in addition to CQ.[13] Some co-initiators and a substance that helps the interaction between some elements within this resin are present. This will produce more radical polymerization initiators and will increase the degree of conversion (DC). Some photoinitiator systems absorb violet light to be excited,[12] generating the expectation that the light emitted by the light-curing unit (LCU) must have the corresponding wavelength for this photoinitiator to result in a sufficient DC of the resin cement.[14]

Light-emitting diode (LED) LCUs have an emission peak (monowave) that corresponds to the CQ absorption spectrum (470 nm).[15] The more recent generation of LED LCUs is considered to include broad spectrum devices. These exhibit two or more emission peaks with narrower violet wavelengths (approximately 410 nm) to activate alternative photoinitiators and blue wavelengths to activate CQ.[16,17] To improve the process of photoactivation in materials that have these newer photoinitiators, the SDI Ltd (Victoria, Australia) has introduced a new LCU with monowave and multiwave interchangeable tips.

The authors found no studies that investigated the effect of the same LCU, which emits monowave and multiwave light, on the mechanical properties of different resin cements containing different photoinitiators. Therefore, this study aimed to evaluate the effect of light emitted by the same LCU with monowave and multiwave tips on the mechanical properties of different light-cured resin cements with different photoinitiators at different locations of the simulated ceramic of a maxillary central incisor. The null hypothesis was that the mono- or multiwave light emitted by the same LCU would not affect the Knoop

hardness (KH, N/mm²) and DC of light-cured resin cements, regardless of the type of photoinitiator and the region of the restoration.

METHODS AND MATERIALS

Specimen Preparation

Three light-cured resin cements with different photoinitiators were investigated in this study (see Table 1): Megalink Esthetic (Odontomega, São Paulo, Brazil) with a CQ photoinitiator, Allcem Veneer (FGM, Joinville, Brazil) with the APS system, and Variolink Esthetic LC (Ivoclar Vivadent, Schaan, Liechtenstein) with Ivocerin. This LCU has interchangeble tips, and the light emitted by each of the tips (monowave and multiwave) were characterized using a 12.5-inch integrating sphere (Labsphere, North Sutton, NH, USA) connected to a fiber-optic spectrometer (USB 4000, Ocean Insight, Largo, FL, USA) to measure the total radiant power (mW), irradiance (mW/cm²), and spectrum (mW/cm²/nm). The internal and external tip diameters of the LCU were measured using digital calipers (Mitutoyo, Tokyo, Japan). The tip area was calculated using the inner diameter of the light tip.

A lithium disilicate ceramic block (IPS e.max CAD, Ivoclar Vivadent) HT/A1/C14 was cut to a thickness of 0.5 mm using a precision saw (Isomet 1000, Buehler, Lake Bluff, IL, USA). The simulated veneer ceramic specimens were crystallized in a dental furnace (Programat EP 3010, Ivoclar Vivadent) according to the guidelines of the manufacturer. A 0.3-mm-thick transparent acetate plate was used to produce a maxillary central incisor-shaped matrix to insert the resin cement. A matrix with 10-mm-high cervical-incisal and 9-mm mesial-distal dimensions was prepared using a diamond bur (#3122, KG Sorensen, São Paulo, Brazil). A Mylar strip was positioned over the glass plate, the acetate matrix was positioned over the Mylar, and the resin cement was mixed and injected into the matrix. Another Mylar strip was used to cover the resin cement before positioning the 0.5-mm-thick ceramic.

Three resin cement specimens were light-cured using both LCU heads, resulting in six experimental groups (n=5). This sample size was defined after a pilot study and also considered in a previous study with similar study design.[13] The LCU was positioned using a specific support (Odeme Dental Research, Santa Catarina, Brazil) for stabilization during light activation. The resin cement was then inserted into the matrix and activated for 40 seconds. After 24 hours of dry storage at 37°C in the dark, the resin cement specimens were submitted to the mechanical tests.

Raman Spectroscopy

A LabRam HR Evolution Raman spectrometer (Horiba LabRam, Villeneuve d'Ascq, France) was used to evaluate the DC of the resin cements. The measurements were performed 24 hours after specimen preparation. The DC was evaluated for five regions: cervical, mesial, central, distal, and incisal on the top surface of each resin cement specimen. The parameters used at the time of the test were as follows: centered spectrum of 1300 cm^{-1}, acquisition time of 15 seconds, nine repetitions per measurement, DuoScan (HOYA UV-VIS colored glass bandpass filter, Edmund Industrial

Table 1: *Information on the Resin Cements Used in This Study, Provided by Manufacturers*

Name	Manufacturer	Composition	Photoinitiator	Shade
Allcem Veneer	FGM	Methacrylate monomers, camphorquinone, co-initiators, stabilizers, pigments, silanized barium, aluminum, silicate glass particles, and silicon dioxide	APS System	Translucent
Megalink Esthetic	Odontomega	Barium glass based on Bis-GMA matrix of dental resins, additives, catalysts, pigments	Camphorquinone	Transparent
Variolink Esthetic LC	Ivoclar Vivadent	Matrix: Urethane dimethacrylate and further methacrylate monomers. Fillers: ytterbium trifluoride and spheroid mixed oxide Initiators, stabilizers, and pigments are additional ingredients.	Ivocerin	Translucent

Abbreviation: Bis-GMA, bisphenol A-glycidyl methacrylate.

Optics, Barrington, NJ, USA) dot off, target of x100Vis, grid of 600 gr/mm, neutral density filter (5.0 and 0.5, Edmund Industrial Optics, Barrington, NJ, USA) of 25%, laser of 532 nm (100%=50 mW), hole of 400, visible range, estimated time of 2 minutes and 15 seconds per spectrum.

Postprocessing of the spectra was performed using OriginPro 2018 software (OriginLab Corporation, Northampton, MA, USA) in which aliphatic and aromatic peaks were integrated. DC values were calculated using the following equation:

$$DC\,(\%) = \left(\frac{R\,(polymerized)}{R\,(non-polymerized)}\right) \times 100,$$

where R is the ratio of aliphatic and aromatic peak areas at 1637 and 1608 cm^{-1} in polymerized and nonpolymerized resin cements. One specimen of each nonpolymerized material was also tested to record the baseline reference material data.

Microhardness Testing

KH was measured after 24 hours using a KH indentation (MicroMet 5104, Buehler) with a load of 50 gf applied for 15 seconds at five different locations: cervical, mesial, central, and distal, and incisal of the simulated central incisor matrix shape. Three indentations were made in each region, totaling 15 indentations per specimen, with a spacing of 1 mm between them. Finally, the average of three measurements was calculated to represent each location.

Light Transmission – Beam Profiling

The beam profiles of the light emitted by both LCU heads with and without the interposition of the ceramic and resin cements were examined. The light beam was examined from the other side of the tip using a profile camera with a 50-mm focal length lens (SP928, Ophir-Spiricon, Logan, UT, USA) with two blue filters (HOYA UV-VIS colored glass bandpass filter, Edmund Industrial Optics, Barrington, NJ, USA) and two neutral density filters (5.0, 0.5, Edmund Industrial Optics). To compare all radiant powers emitted by the LCUs in the beam profile, the integration time was first acquired for each LCU until no pixels were saturated from the most powerful LCU. The same settings were used to record all beam profile images from the LCUs used in this study. To characterize the LCUs, a 60-degree holographic diffuser screen (Edmund Optics) was used, and the images were captured through this filter, which was then removed. The ceramic veneer with and without resin cement was positioned, and the images were captured using these materials. Images were collected using specific software (Beam Gage Professional 6.14.0.355 software, Ophir-Spiricon).

Statistical Analysis

The DC and KH data were analyzed for normal distribution using the Shapiro–Wilk test and equality of variances using Levene tests. Data were analyzed by two-way repeated measures–analysis of variance (RMANOVA) to compare the following study factors: type of resin cement (three levels), type of light (two levels), and region (five levels) for each specimen. Multiple comparisons were performed using the Tukey *post hoc* test. All tests used a significance level of α = 0.05, and all analyses were performed using Sigma Plot 12.5 (Systat Software Inc, San Jose, CA, USA).

RESULTS

The characteristics of the different tips, mono- and multiwave, are listed in Table 2. Figure 1 presents the spectra of two tips: monowave (single peak at 450 nm) and multiwave (double peaks at 400 and 448 nm). Both tips maintained stable power for 20 seconds (Figure 2).

The DC means and standard deviations for all tested groups are shown in Table 3. Two-way RM ANOVA showed a significant effect only for the type of cement (p<0.001). Allcem Veneer (FGM) presented significantly higher DC values than the other resin cements, whereas Variolink Esthetic (Ivoclar Vivadent) had a significantly lower DC value than Megalink Esthetic (Odontomega). There was no significant effect from light type (p=0.594), region (p=0.168), or interaction between the study factors (p=0.736).

The KH means and standard deviations for all tested groups are shown in Table 4. Two-way RM ANOVA showed a significant effect for the type of resin cement (p<0.001), type of light (p<0.001), region (p<0.001), and interaction between the type of resin cement and LCU (p<0.001). No significant differences were observed from interactions among the three factors (p=0.978).

For all of the cements, the multiwave light source was inferior to the monowave source. The resin cement with

Table 2: *Characteristics of Different Tips (Monowave and Multiwave)*

	Internal Tip Diameter (mm)	Power (mW)	Irradiance (mW/cm²)
Radii Xpert monowave	7.8	439.0	914.7
Radii Xpert multiwave	7.8	512.1	1066.8

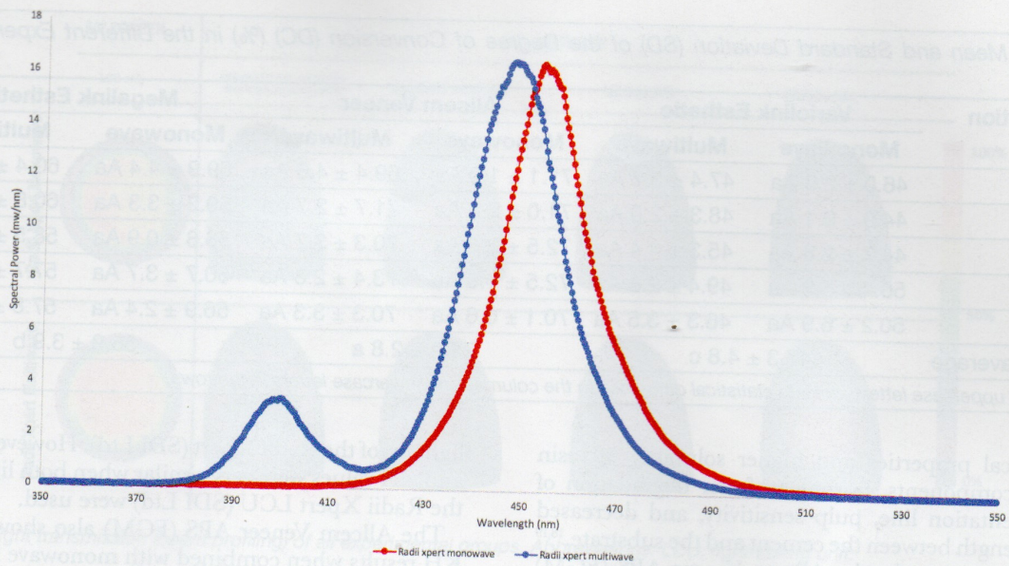

Figure 1. *Spectrum of both tips: monowave (single peak in 450 nm) and multiwave (double peak in 400 and 448 nm).*

the APS photoinitiator photocured with monowave light exhibited the highest KH values, mainly in the buccal region (center). The beam-profiling images of the light transmission of the LCU and those transmitted through the ceramic/resin cements are shown in Figure 3. These showed a greater incidence of light from the LCU in the vestibular region of the samples, regardless of whether it was monowave or multiwave light.

DISCUSSION

The DC values were influenced by the type of resin cement, whereas the KH values were influenced by the type of resin cement as well as the interaction between the LCU, resin cement, and the location of restoration. Therefore, the null hypothesis was rejected.

The DC is considered a parameter that directly reflects the mechanical properties of the resin cement material.[18] A lower DC value could result in lower

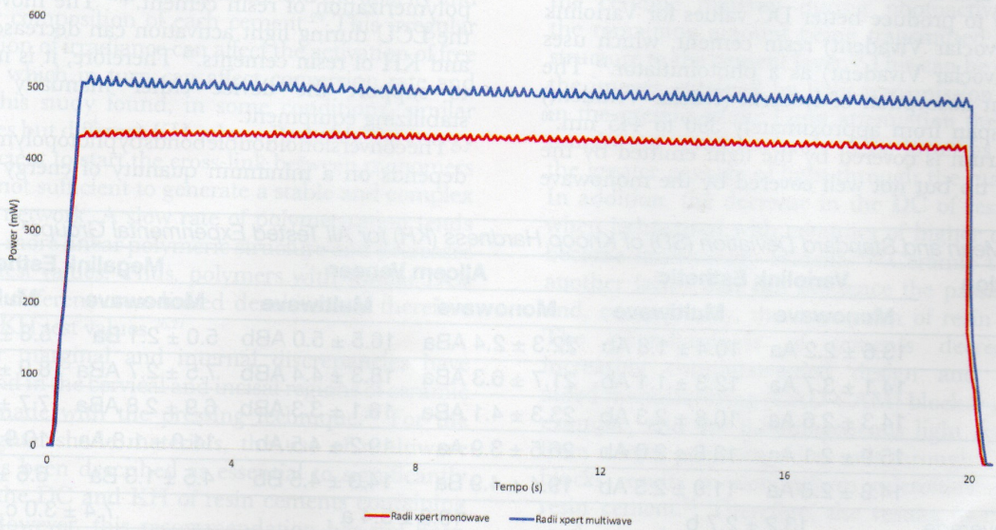

Figure 2. *Both spectrums maintained the power stable during 20 seconds.*

Table 3: *Mean and Standard Deviation (SD) of the Degree of Conversion (DC) (%) in the Different Experimental Groups*[a]

Location	Variolink Esthetic		Allcem Veneer		Megalink Esthetic	
	Monowave	Multiwave	Monowave	Multiwave	Monowave	Multiwave
Cervical	46.0 ± 2.9 Aa	47.4 ± 3.7 Aa	71.1 ± 1.9 Aa	69.4 ± 4.6 Aa	59.9 ± 4.4 Aa	60.4 ± 7.9 Aa
Mesial	44.9 ± 9.1 Aa	48.3 ± 2.0 Aa	71.0 ± 2.8 Aa	71.7 ± 2.7 Aa	59.2 ± 3.3 Aa	60.8 ± 2.9 Aa
Distal	44.7 ± 2.8 Aa	45.3 ± 4.4 Aa	72.5 ± 2.6 Aa	70.3 ± 3.7 Aa	56.8 ± 0.9 Aa	58.5 ± 2.9 Aa
Buccal	50.4 ± 5.2 Aa	49.4 ± 2.8 Aa	72.5 ± 1.6 Aa	73.4 ± 2.3 Aa	60.7 ± 3.7 Aa	57.7 ± 4.6 Aa
Incisal	50.2 ± 6.9 Aa	46.3 ± 3.5 Aa	70.1 ± 0.6 Aa	70.3 ± 3.3 Aa	56.9 ± 2.4 Aa	57.8 ± 2.9 Aa
Pooled average	47.3 ± 4.8 c		71.2 ± 2.8 a		58.9 ± 3.9 b	

[a]*Different uppercase letters indicate statistical difference in the columns and lowercase letters in the rows.*

mechanical properties and higher solubility of resin cement components, leading to faster degradation of the cementation line, pulp sensitivity, and decreased bond strength between the cement and the substrate.[18,19] In the present study, the Allcem Veneer APS (FGM) resin cement, which contains the APS system as a photoinitiator, showed better DC values than Variolink Esthetic (Ivoclar Vivadent) and Megalink Esthetic (Odontomega), regardless of the LCU and location. According to the manufacturer, the APS system is a combination of different photoinitiators, including CQ, which is better absorbed by blue light, justifying its indifference to the use of multiple and monowave lights, considering that violet light has less penetration in this type of photoinitiator. The sensitivity of the APS system was more effective than that of CQ, which is present in Megalink Esthetic (Odontomega) cement. This study also confirmed that a multiwave LCU is not mandatory to produce better DC values for Variolink Esthetic (Ivoclar Vivadent) resin cement, which uses Ivocerin (Ivoclar Vivadent) as a photoinitiator.[13] The visible light absorption of Ivocerin (Ivoclar Vivadent) seems to span from approximately 390 to 445 nm.[20] This spectrum is covered by the light emitted by the multiwave tip but not well covered by the monowave light tip of the Radii Xpert (SDI Ltd). However, the DC and KH values were very similar when both light tips of the Radii Xpert LCU (SDI Ltd) were used.

The Allcem Veneer APS (FGM) also showed better KH results when combined with monowave light. The center of the specimen exhibited the highest results. In a photopolymerization system with more than one light source, violet light is less intense since it has an intermediate ceramic layer, which receives less light. As expected, the central region exhibited the best results. This explains the reason for the shadow area on the margins of a ceramic, as the diameter of the LCU is smaller than the diameter of a maxillary central incisor. Therefore, it was necessary to activate at least two light spots to cover the entire restoration area. In addition, other precautions are necessary during the light-curing of resin cement materials.[17] The stabilization of the LCU is one of the main factors involved in the complete polymerization of resin cement.[13,17] The movement of the LCU during light activation can decrease the DC and KH of resin cements.[13] Therefore, it is important to support the device either manually or with stabilizing equipment.

The conversion of double bonds by photopolymerization depends on a minimum quantity of energy to excite

Table 4: *Mean and Standard Deviation (SD) of Knoop Hardness (KH) for All Tested Experimental Groups*[a]

Location	Variolink Esthetic		Allcem Veneer		Megalink Esthetic	
	Monowave	Multiwave	Monowave	Multiwave	Monowave	Multiwave
Cervical	13.6 ± 2.2 Aa	10.4 ± 1.8 Ab	22.3 ± 2.4 ABa	16.5 ± 5.0 ABb	5.0 ± 2.1 Ba	5.8 ± 1.4 Ba
Mesial	14.1 ± 3.7 Aa	12.3 ± 1.1 Ab	21.7 ± 6.3 ABa	18.3 ± 4.4 ABb	7.5 ± 2.7 ABa	8.0 ± 2.3 Aa
Distal	14.3 ± 2.6 Aa	10.8 ± 2.3 Ab	23.3 ± 4.1 ABa	16.1 ± 3.3 ABb	6.9 ± 2.8 ABa	7.7 ± 3.4 Aa
Buccal	15.9 ± 2.1 Aa	13.8 ± 2.0 Ab	26.5 ± 3.9 Aa	19.2 ± 4.5 Ab	11.0 ± 1.8 Aa	10.9 ± 2.5 Aa
Incisal	14.8 ± 2.6 Aa	11.9 ± 2.3 Ab	19.4 ± 4.9 Ba	14.3 ± 4.5 Bb	4.5 ± 1.3 Ba	6.6 ± 3.1 Ba
Pooled average	13.2 ± 2.7 b		19.8 ± 5.4 a		7.4 ± 3.0 c	

[a]*Different uppercase letters indicate statistical difference in the columns and lowercase letters in the rows.*

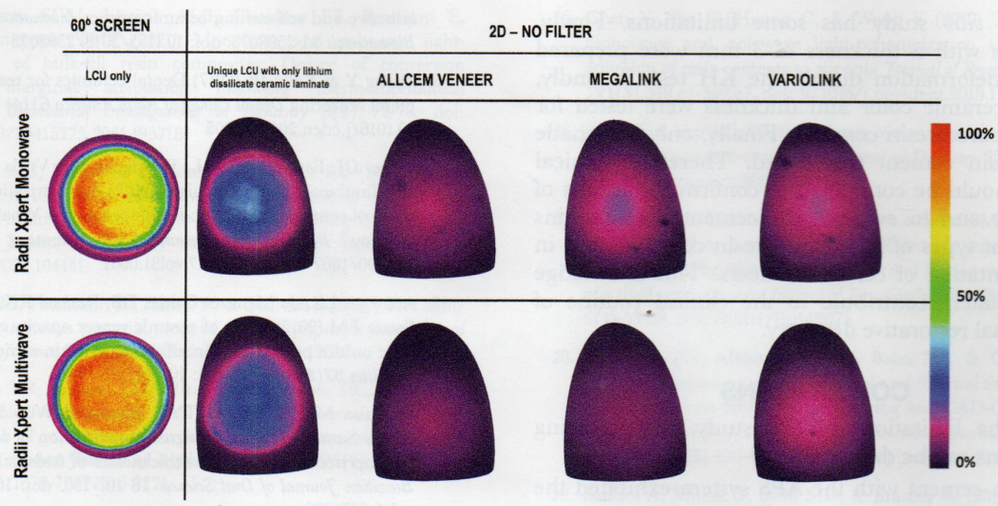

Figure 3. *Light transmission (beam profiling) of all experimental groups. Abbreviations: LCU, light-curing unit.*

the photoinitiator and produce a sufficient number of radicals for polymerization.[18,21] Regarding the properties of cementing agents, the decrease in light energy density, coinciding with a gradual increase in the ceramic thickness, can have a direct impact on decreasing the DC of light-cured resin cements.[18,22] The nonuniform beam profile and nonhomogeneous light transmission emitted by LCUs through ceramic restorations can result in nonuniform KH throughout the entire cement area.[23] The light transmitted through the cemented area differed among the resin cements tested in the present study, and this was likely due to the presence of different photoinitiators and the opacity and the filler composition of each cement.[24] This irregular distribution of irradiance can affect the activation of free radicals, which in turn can affect conversion rate and KH.[25] This study found, in some conditions, similar DC values but different KH values. Probably the energy was sufficient to start the cross-link between monomers but was not sufficient to generate a stable and complex polymer network. A slow rate of polymerization tends to form a more linear polymeric structure and decreases the KH test values. Thus, polymers with similar DCs can have different cross-linked densities and therefore different KH test values.[26,27]

Smaller marginal and internal discrepancies have been found in the cervical and incisal regions of ceramic veneers made with the pressing technique.[28] For the use of lighter-shade materials, the use of multiwave LCUs has been described as essential to significantly improve the DC and KH of resin cements containing TPO.[29] However, this recommendation has not been confirmed for resin cement containing Ivocerin.

Beam profiling analysis demonstrated significant light attenuation produced by the 0.5-mm-thick disilicate ceramic material. Translucency is an optical property of restorative materials that refers to the amount of light capable of being transmitted through its structure, which has a significant influence on the final esthetic result of restorations.[24] As a characteristic linked to the transmittance of ceramic materials, some studies have evaluated the passage of light through different opacities[30,31] and its influence on the polymerization of resinous materials used for cementation.[24] A certain amount of light is reflected or absorbed by the ceramic material during photoactivation, with the remaining amount being transmitted through its structure to the cement layer.[24] This can be observed in the images obtained by light transmission performed in the present study. Light attenuation through more translucent ceramics tends to be lower as a result of the greater passage of light through the material.[24,30,32] In addition, the decrease in the DC of resin cements when light-cured with ceramics of higher opacity has become increasingly evident.[24,33] Ceramic thickness is another factor that can influence the passage of light and, consequently, the conversion of resin cements.[18] The microhardness of cements decreases with increasing computer-aided design and computer-aided manufacturing (CAD-CAM) block thickness, for example, and the inhomogeneous light transmission from a light polymerization unit through CAD-CAM blocks results in nonuniform microhardness of the resin cement.[34] Therefore, the results of the present study may be overestimated if a thicker and opaque ceramic restoration is used.

This *in vitro* study has some limitations. Firstly, specimens with a thickness of 3 mm were prepared to avoid deformation during the KH test. Secondly, a single ceramic color and thickness were tested for the light-cured resin cements. Finally, only one shade of the resin cement was tested. Therefore, clinical studies should be conducted to confirm the results of this study and to evaluate the cementation margins of different types of light-cured resin cements used in the cementation of ceramic veneers. This knowledge will ultimately contribute to the clinical routine of professional restorative dentistry.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

- Resin cement with the APS system exhibited the best results in terms of the DC and KH.
- The LCU, when evaluated between multi- or monowave, may not be a determining factor for the results of the properties of light-cured resin cements.
- The central region of the buccal surface showed the best results for DC and KH, indicating the need for a greater amount of light-curing at the cementation margins.

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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.

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