# Influence of Thickness and Translucency of Lithium Disilicate Ceramic on the Degree of Conversion of Resin Cements with Different Initiators


## Keywords

*Ceramics*
*Fourier-Transform Infrared Spectroscopy*
*Degree Of Conversion*
*Resin Cements*



## Authors

Sinara C. Lima *
*(DDS, MD)*

Andreza C. A. da Silva §
*(DDS)*

Renata Cimões ‡
*(DDS, MD, PhD)*

Bruna C. F. Vajgel ‡
*(DDS, MD, PhD)*

## Address for Correspondence

Bruna C. F. Vajgel ‡

Email: bruna.farias@ufpe.br

* *Doctoral student, Department of prosthesis and oral facial surgery, Federal University of Pernambuco (UFPE), Recife, Pernambuco, Brazil*

§ *Undergraduated student, Department of prosthesis and oral facial surgery, Federal University of Pernambuco (UFPE), Recife, Pernambuco, Brazil*

‡ *Professor, Department of Prosthesis and Oral Facial Surgery, Federal University of Pernambuco (UFPE), Recife, Pernambuco, Brazil*



Received: 27.03.2023
Accepted: 16.08.2023

doi: 10.1922/EJPRD_2552Lima08



## ABSTRACT

*Introduction: The degree of conversion (DC) of resin cements can be affected by ceramics, and by the type of resin cement. The purpose was to evaluate the influence of thickness and translucencies of lithium disilicate ceramic on the DC of resin cements: two light-cure (Variolink LC; NX3 LC) and one dual-cure (NX3 Dual). Methods: IPS e.max Press ceramic (A2) discs were prepared in 4 thicknesses (0.3, 0.5, 1.0, and 1.5 mm) and in 3 translucencies: HT (high translucency), LT (low translucency), and MO (medium opacity). Subsequently, 234 samples of resin cement (5 x 1 mm) were light-cured through those ceramic discs. The DC was assessed by Fourier Transform Infrared Spectroscopy (FTIR). Results: Ceramic thicknesses decreased DC of NX3 Dual through HT-1.0 and HT 1.5 (p=0.005). Between translucencies, only MO-0.3 affected Variolink LC DC (p=0.018). There was difference among light- and dual-cured resin cements (p=0.001). Conclusion: Increasing thickness and opacity lead to a decrease in the DC of all resin cements, with a significantly lower DC value in NX3 Dual (HT-1.0; HT-1.5), and in Variolink LC (MO-0.3). Light- and dual-cured resin cements were different among each other. NX3 Dual achieved a significantly lower value than its counterpart NX3 LC.*


## INTRODUCTION

Dental ceramic restorations based on lithium disilicate are extensively used in oral rehabilitation procedures.[1-3] Crowns, conventional veneers, ultra-thin veneers, occlusal veneers, and other partial dental restorations are some clinical applications for lithium disilicate ceramics, thanks to the variety of available translucencies, greater mechanical strength than in traditional feldspathic glass, and the ability to modify fit surfaces.[4-6] Such a range of clinical applications and their long-term success is determined in part by the cementation and resin cement layer, which can be influenced by the thickness and translucency of the indirect restoration, as well as by the type of resin cement employed.[1,7,8]

An important factor regarding the long-term success of a dental veneer is the influence of ceramics on the conversion of resin cement monomers into polymers.[4,9,10] Some characteristics inherent to ceramics can influence

the degree of conversion (DC), such as the ceramic's type, thickness, and translucency.[11-13] The greater the thickness, the lower the light energy that reaches underneath resin cement.[14-16] Studies show that thicker ceramics are related to higher short-wavelength absorbance (violet 380 – 420 nm); however, thickness seems not to affect longer wavelength light transmittance (blue 450 – 495 nm).[14,17-22] Translucency is an optical characteristic of materials, which defines the amount of light transmitted through their structure.[2,23] When light is activated through ceramic materials, some light is reflected or absorbed, and the remaining light passes through them.[2,18,23] Some factors importantly influence ceramic translucency, including color saturation, crystal structure, thickness, number of firing cycles, size of crystalline particles, pigments, and so on.[3,18,24] These characteristics may affect light transmittance from the light-curing unit (LCU) to the resin cement layer.[3,8,12,24]

Other characteristics inherent to resin-based materials also influence DC: type and amount of inorganic and organic matrix and type and amount of the photoinitiator system.[10,15] Lower DCs are associated with excessive residual monomers, whose leaching by water diffusion directly affects the strength and stability of adhesive bonding, hardness, elastic modulus, flexural strength, and increased porosity of the resin cement, compromising the integrity of the tooth structure and longevity of indirect restoration.[1,14,25-29] DC in resin cements based on bisphenol A diglycidyl methacrylate (Bis-GMA) or similar monomers ranges from 39% to above 50%.[30-33] On the other hand, resin cements whose organic matrix is based on urethane dimethacrylates (UDMA) have greater DC, up to 65%.[33,34] A recent systematic review claims that resin cement DC should range from 60 to 75% to reach optimal clinical parameters;[6] however, these *in vitro* optimal DC results cannot be translated into clinical practice.[20,35,36] Resin cements are classified according to filler particle size (micro and nano), method of bonding (total-etch and self-etch), and type of cure (chemical, dual or photoactivated).[25,26,37] Dual-cure resin cements depend on exposure to light and chemical curing to produce enough free radicals to convert monomer into polymer, thus improving their physical and mechanical properties.[29,37-40] However, those resin cements usually have tertiary amines in their composition, which act as co-initiators of the curing process and compromise long-term color stability.[25,41-44] Handling dual resin cements leads to interaction with oxygen, which can affect some properties such as hardness and roughness. Then, to minimize this reaction with atmospheric air, some manufacturers have developed self-mixing tips.[10,15]

Camphorquinone (CQ) is a Norrish type II photoinitiator that needs an electron donor molecule, usually a tertiary amine, to trigger the formation of free radicals. These radicals react with the methacrylate monomers and start the curing process. However, the tertiary amine present in CQ materials compromises color stability.[15,44,45] Currently, some cements have been using Norrish type I photoinitiators (amine-free initiator system), such as Ivocerin, TPO (2,4,6-trimethylbenzoyl diphenylphosphine oxide), and BAPO (2,4,6-Trimethylbenzophenone) in their formulation, which does not require co-initiators. Those, when exposed to light, undergo a cleavage, and the molecule splits into two or more free radicals that lead to polymerization.[25,26,42,44,46] Additionally, some type I photoinitiators are not activated by blue light (450 to 495 nm); instead, they require short wavelengths from the violet spectrum (380 to 420 nm).[15,26,42,44,46,47] On the other hand, Ivocerin, which is one photoinitiator from Variolink LC, absorbs light in both violet and blue ranges of the spectrum to achieve adequate polymerization.[21,22]

Several studies have analyzed DC in resin cements with Norrish type I photoinitiators when light-cured with different sources of LCU and through different types of ceramics, thicknesses, and translucencies;[21-23,26,44-46,48-52] yet, just few of them used polywave LCUs[21-23,46,48,50,52] and compared brands of resin cements with amine-free initiator systems (as reported by manufactures).[21,22,48] For that reason, the main objective of the present study was to evaluate the influence of thickness and translucency of lithium disilicate ceramic on DC of resin cements with amine-free initiator systems: two light-cure (Variolink Esthetic LC – light-cure; and NX3 LC) and one dual-cure resin cement (NX3 Dual), when activated by a polywave LCU (395 nm to 480 nm, 1000 mW/cm$^2$, 20s). The following null hypotheses were tested: a) the DC of resin cements cured in the same conditions were not affected by thickness of lithium disilicate ceramics; b) the DC of resin cements cured in the same conditions were not affected by translucency of lithium disilicate ceramics; and, c) there was no difference between the DC of light- and dual-cure resin cements.

## MATERIALS AND METHODS

The thickness of crowns and veneers is inhomogeneous. Hence, to experimentally reproduce such variability of veneer thickness, IPS e.max Press ceramic discs (Ivoclar Vivadent AG, Schaan, Liechtenstein) with 10 mm in diameter were made in four thicknesses (0.3 mm, 0.5 mm, 1.0 mm, 1.5 mm), color A2, and in three translucencies (HT, LT, and MO) according to manufacturer specifications (n=3 discs for each thickness/translucency, totaling 36 ceramic discs). A prototype of the discs was designed in exocad GmbH and 3D printed. These discs were included in the injection ring and heat-pressed using the lost-wax technique by a prosthetics technician.[7,36,45,46,49,53]

A radiometer (Hilux Ledmax curing light meter, Benlioğlu Dental Inc., Ankara, Turkey) was used to confirm the irradiance of the LCU (VALO LED Ultradent Inc., South Jordan, Utah, United States). Initially, to standardize LCU LED temperature, the LCU was activated for 60 s before light-curing ([54,55]). For each ceramic disc, two samples of each evaluated resin cement were made *(Table 1)*. Then, it resulted in six resin cement samples per investigated group according to the type of resin cement, thickness, and translucency of the ceramic disc. Additionally, a control group with six samples of each resin cement was made without the interposition of the ceramic disc, totaling 234 resin cement samples, 78 samples for each type of resin cement.

**Table 1.** Main characteristics and chemical composition of resin cements.

| Product | Manufacturer | Lot | Shade | Initiator | Content* |
|---|---|---|---|---|---|
| **Variolink LC** | Ivoclar Vivadent AG, Schaan, Liechtenstein | Y43728; Z014KC | Light | Ivocerin (benzoyl germanium) | ytterbium trifluoride, UDMA, D3MA. |
| **NX3 LC** | Kerr Corp., Orange, California, United States | 7441520; 7558135; 8016077 | White | REDOX system (free from tertiary amine and benzoyl peroxide) | Bis-EMA, Bis-GMA, TEGDMA, HEMA, UDMA, MEMO, ytterbium trifluoride. |
| **NX3 Dual** | Kerr Corp., Orange, California, United States | 7927410; 7452376 | White | REDOX system<br>Co-initiator: EDMAB | Base: Bis-EMA, Bis-GMA, UDMA, TEGDMA, HEMA, EDMAB, MEMO, ytterbium trifluoride.<br>Catalyst: TEGDMA, Bis-EMA, Bis-GMA, UDMA; HEMA, MEMO, ytterbium trifluoride, Cumene Hydroperoxide. |

*As described by the manufacturer (Safety data sheets (SDS)). UDMA: Urethane dimethacrylate; D3MA: 1,10-decandiol dimethacrylate; Bis-EMA: bisphenol A diglycidyl methacrylate ethoxylated; Bis-GMA: bisphenol A diglycidyl methacrylate; TEGDMA: triethylene glycol dimethacrylate; HEMA: Hydroxyethylmethacrylate; EDMAB: Etyl 4-dimetyl aminobenzoate; MEMO: metacryloxipropyltrimetoxisilane.

Resin cement samples *(Table 1)* were shaped from a polyvinylsiloxane mold (Virtual, Ivoclar Vivadent AG, Schaan, Liechtenstein) with 5 mm in diameter and 1 mm in depth.[52] Due to the characteristics of the material, the mold was used after 1 hour of its making.[25,26,41,43,56-58] The resin cement was deposited directly inside the mold, and a transparent polyester strip was placed over the mold/cement set to inhibit contact with atmospheric oxygen and facilitate the positioning of the ceramic disc.[25,26,58] Then, to regularize sample thickness, the polyester strip was pressed manually with a straight spatula number 24 (Golgran, São Caetano do Sul, São Paulo, Brazil). Afterward, the ceramic disc was placed on the polyester strip. Subsequently, the resin cement was light-cured with the LCU for 20 s, in Standard mode, with the LED tip perpendicular and in contact with the ceramic disc.[1,12,20]

The steps were conducted in a room with no artificial light interference. Before measuring the DC, the samples were stored under dry and dark conditions at 37ºC for 24h.[6,40,43-45,49,53,57] Resin cements handling followed the manufacturer's instructions, and the dual-cure resin cement was mixed with the automix tip supplied by the manufacturer.

The DC of resin cement was determined using Fourier Transform Infrared Spectroscopy (FTIR) associated with attenuated total reflectance (ATR) (PerkinElmer FT-IR/FT-NIR Spectrometer, model: spectrum 400; Miracle accessory ATR unit, spectrum 100, diamond/ZnSe – Waltham, Massachusetts, United States).

Each sample was scanned 32 times with 4,000 to 400 $cm^{-1}$ of range, and 4 $cm^{-1}$ resolution.[36,44] Moreover, the sample side in contact with the polyester strip was placed facing the diamond of the ATR unit. First, a reading of the resin cement in its uncured form was performed. Then, all readings were made at the center of the sample. Further, the ratio between the aliphatic and the aromatic carbon group for uncured and cured samples, respectively, was used to calculate the DC according to the following equation:[3,25,26,36,49,53,55]

$$DC\ (\%) = 1 - (R\ polymer)/(R\ monomer)\ \times\ 100$$

In which R is the ratio between the absorbance peak of C=C aliphatic bonds at wavelength 1637 $cm^{-1}$, and the absorbance peak of aromatic bonds at 1609 $cm^{-1}$ for all resin cements studied.

Data normality was verified by Shapiro-Wilk test ($p < 0.05$). The influence of thickness and translucency on DC were analyzed by Mann-Whitney test between two independent categories and by Kruskal-Wallis test for more than two independent categories. Data were reported by mean ± standard deviation (a = 0.05).

# RESULTS

Comparative analysis of resin cement DC means according to thickness within each translucency of ceramic is shown in table 2. It was observed that increasing thicknesses, within each translucency group, reduced resin cement DC. Moreover, NX3 Dual samples exhibited statistical differences between thickness 1.0 and 1.5 mm of HT translucency (p-value3 = 0.005).

Translucencies reduced the DC of all tested resin cements. Comparing DC results among translucencies (HT, LT, and MO) with the same thickness, only Variolink LC presented a significant difference under MO 0.3 mm (p5 = 0.017) *(Table 3)*.

DC differs significantly between the types of cement (p-value4 < 0.05). Variolink LC had the highest DC means ± SD for LT 0.3 (82.92 ± 3.93%) and HT 0.3 (82.3 ± 1.53%) groups, and NX3 Dual presented the lower DC mean in the MO 1.5 group (33.92 ± 3.22%). In general, the DC means of the groups were closer to the control group. Further, comparing DC among light-cured resin cements, Variolink LC (Ivocerin) had a higher DC than NX3 LC (REDOX) *(Figure 1)*.

**Table 2.** Comparative analysis of resin cement DC means according to thickness within each translucency of ceramic.

| Translucency | Thickness | N | Resin Cement | | | | | | p-value[4] |
|---|---|---|---|---|---|---|---|---|---|
| | | | Variolink LC | | NX3 LC | | NX3 Dual | | |
| | | | Mean ± SD | p-value[1] | Mean ± SD | p-value[2] | Mean ± SD | p-value[3] | |
| Control | 0.0 | 6 | 81.78 ± 1.49 a | - | 54.40 ± 7.64 b | - | 44.42 ± 3.37 c | - | 0.001* |
| HT | 0.3 | 6 | 82.30 ± 1.53 Aa | 0.273 | 53.12 ± 3.22 Ab | 0.419 | 41.26 ± 3.52 Ac | 0.005* | 0.001* |
| HT | 0.5 | 6 | 81.13 ± 4.40 Aa | | 52.26 ± 7.18 Ab | | 40.84 ± 1.90 Ac | | 0.001* |
| HT | 1.0 | 6 | 81.19 ± 4.22 Aa | | 51.77 ± 4.38 Ab | | 36.99 ± 3.96 Bc | | 0.001* |
| HT | 1.5 | 6 | 82.15 ± 4.00 Aa | | 51.22 ± 2.05 Ab | | 36.30 ± 3.39 Bc | | 0.001* |
| LT | 0.3 | 6 | 82.92 ± 3.93 Aa | 0.419 | 52.25 ± 6.87 Ab | 0.931 | 38.78 ± 2.60 Ac | 0.686 | 0.001* |
| LT | 0.5 | 6 | 82.37 ± 1.81 Aa | | 50.34 ± 5.43 Ab | | 37.58 ± 1.83 Ac | | 0.001* |
| LT | 1.0 | 6 | 80.96 ± 5.64 Aa | | 50.53 ± 10.33 Ab | | 37.73 ± 1.66 Ac | | 0.001* |
| LT | 1.5 | 6 | 80.05 ± 8.08 Aa | | 50.10 ± 7.96 Ab | | 37.70 ± 2.37 Ac | | 0.001* |
| MO | 0.3 | 6 | 79.03 ± 4.07 Aa | 0.773 | 51.08 ± 9.86 Ab | 0.729 | 38.65 ± 4.97 Ac | 0.100 | 0.001* |
| MO | 0.5 | 6 | 78.87 ± 7.55 Aa | | 49.90 ± 6.55 Ab | | 37.49 ± 3.42 Ac | | 0.001* |
| MO | 1.0 | 6 | 78.64 ± 6.99 Aa | | 49.80 ± 5.21 Ab | | 37.02 ± 2.67 Ac | | 0.001* |
| MO | 1.5 | 6 | 76.75 ± 11.09 Aa | | 48.79 ± 9.91 Ab | | 33.92 ± 3.22 Ac | | 0.001* |

*** Statistically significant; 1- Kruskal Wallis test between Variolink LC within each Translucency comparing the mean DC values between the types of thickness; 2- Kruskal Wallis Test between NX3 LC within each Translucency comparing the mean DC values between the types of thickness; 3- Kruskal Wallis test between NX3 Dual within each Translucency comparing the mean DC values between the types of thickness; Means (standard deviations) followed by different letters (upper case comparing thickness and lower case comparing cements) indicate a statistical difference (p≤0.05) using the Mann-Whitney test.**

# DISCUSSION

Under the circumstances of the present *in vitro* study, all thickness and translucency of ceramics reduced the DC of the tested resin cements; however, most of these decrease in DC were not significant. The first null hypothesis was partially accepted, as HT translucency groups from NX3 Dual with thicknesses 1.0 and 1.5 mm were statistically different from 0.3 and 0.5 mm thickness. That hypothesis is in accordance with the findings of the systematic review by Martins *et al.*,[5] whose meta-analysis showed that ceramic thicknesses (1.0, 1.5, 2.0, and 3.0 mm) affected DC; likewise, other studies also reported a significant influence of thickness on DC.[14,16]

Several studies have reported the influence of thickness, translucency, type, and shade of ceramics on the DC of resin cements.[5,6,12,24,28,37,41,53,55,56]). Therefore, the different types of resin cements reported in the literature showed reduced DC when the thickness and opacity of the indirect restoration increased.[10-13,56] These findings agree with the present research, in which resin cements with thicknesses of 0.3 and 0.5 mm had higher DC than those with 1.0 and 1.5 mm. However, few studies have analyzed the influence of different ceramic thicknesses and translucencies in the DC of resin cements with Norrish type I photoinitiators when cured with high-power LCU.[21,22,26,48] Further, other studies have been using Ivocerin in experimental resin cement formulations to increase DC.[44,45]

Since ceramic translucency directly affects the wavelength transmittance of reach resin cement, there is evidence reporting light transmittance decrease when opacity increases, leading to a reduction in DC.[2,12,15,23,50,55,56] Analyzing 1.7 mm-thick ceramic, Queiroz *et al.*[23] reported a statistically significant decrease in DC of Variolink LC with MO translucency, in comparison with LT and HT. In the present study, the same was observed by analyzing 0.3 mm-thick ceramic, where DC of Variolink LC under MO translucency was statistically different from HT and LT. On the other hand, despite the influence of translucency on DC, some studies show that resin cement DC relies much more on the thickness and microstructure of the indirect restoration than on translucency itself.[5,6,14,16, 36,49,50] For example, De Jesus *et al.*[4] claimed that different opacities (HT, LT, and MO) did not influence light transmittance and DC of the tested resinous materials and that the HT, LT, and MO 1.5 mm-thick ceramic let enough light pass through and properly convert the resin cements. That results are in agreement with what the present study reported, where most of translucencies were not statically different.

**Table 3.** Comparative analysis of resin cement DC means according to translucency within each thickness of ceramic.

| Thickness | Translucency | N | Resin Cement | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Variolink LC | | NX3 LC | | NX3 Dual | | p-value[8] |
| | | | Mean ± SD | p-value[5] | Mean ± SD | p-value[6] | Mean ± SD | p-value[7] | |
| Control | | 6 | 81.78 ± 1.49 a | - | 54.40 ± 7.64 b | - | 44.42 ± 3.37 c | - | 0.001* |
| 0.3 | HT | 6 | 82.30 ± 1.53 Aa | | 53.12 ± 3.22 Ab | | 41.26 ± 3.52 Ac | | 0.001* |
| 0.3 | LT | 6 | 82.92 ± 3.93 Aa | 0.017* | 52.25 ± 6.87 Ab | 0.849 | 38.78 ± 2.60 Ac | 0.366 | 0.001* |
| 0.3 | MO | 6 | 79.03 ± 4.07 Ba | | 51.08 ± 9.86 Ab | | 38.65 ± 4.97 Ac | | 0.001* |
| 0.5 | HT | 6 | 81.13 ± 4.40 Aa | | 52.26 ± 7.18 Ab | | 40.84 ± 1.90 Ac | | 0.001* |
| 0.5 | LT | 6 | 82.37 ± 1.81 Aa | 0.399 | 50.34 ± 5.43 Ab | 0.644 | 37.58 ± 1.83 Ac | 0.051 | 0.001* |
| 0.5 | MO | 6 | 78.87 ± 7.55 Aa | | 49.90 ± 6.55 Ab | | 37.49 ± 3.42 Ac | | 0.001* |
| 1.0 | HT | 6 | 81.19 ± 4.22 Aa | | 51.77 ± 4.38 Ab | | 36.99 ± 3.96 Ac | | 0.001* |
| 1.0 | LT | 6 | 80.96 ± 5.64 Aa | 0.854 | 50.53 ± 10.33 Ab | 0.828 | 37.73 ± 1.66 Ac | 0.895 | 0.001* |
| 1.0 | MO | 6 | 78.64 ± 6.99 Aa | | 49.80 ± 5.21 Ab | | 37.02 ± 2.67 Ac | | 0.001* |
| 1.5 | HT | 6 | 82.15 ± 4.00 Aa | | 51.22 ± 2.05 Ab | | 36.30 ± 3.39 Ac | | 0.001* |
| 1.5 | LT | 6 | 80.05 ± 8.08 Aa | 0.423 | 50.10 ± 7.96 Ab | 0.895 | 37.70 ± 2.37 Ac | 0.191 | 0.001* |
| 1.5 | MO | 6 | 76.75 ± 11.09 Aa | | 48.79 ± 9.91 Ab | | 33.92 ± 3.22 Ac | | 0.001* |

*** Statistically significant; 5- Kruskal Wallis test between Variolink LC within each thickness comparing the mean DC values between the types of translucency; 6- Kruskal Wallis Test between NX3 LC within each thickness comparing the mean DC values between the types of translucency; 7- Kruskal Wallis test between NX3 Dual within each thickness comparing the mean DC values between the types of translucency; Means (standard deviations) followed by different letters (upper case comparing thickness and lower case comparing cements) indicate a statistical difference (p≤0.05) using the Mann-Whitney test.**

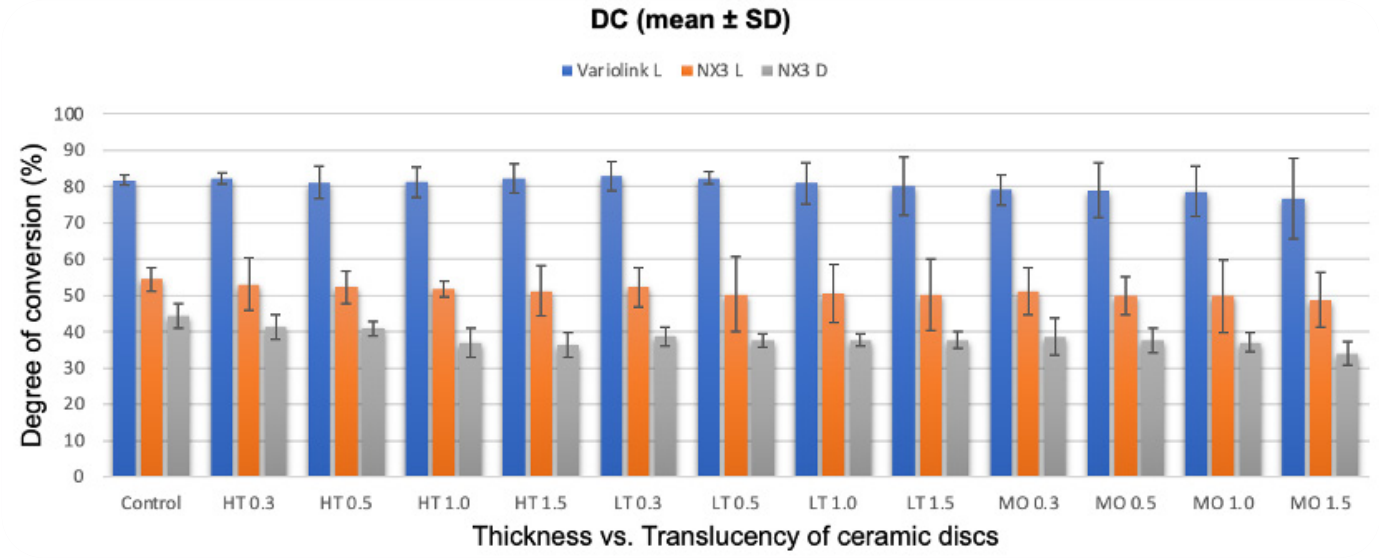


**Figure 1:** Bar chart with the DC means of each resin cement according to thickness and translucency of the ceramic disc.

Although chemical composition varies between manufactures and among light and dual resin cements, Variolink LC showed significantly higher DC when compared to NX3 LC and NX3 Dual. Thus, there was a significant difference comparing light and dual-cure resin cements; then, the third null hypothesis was rejected.

Usually, dual-cure resin cements exhibit higher DC than their light-cure counterparts.[23,51,52,59] However, in the present study, the results of NX3 LC and Dual, which are from the same manufacturer, showed that NX3 LC had higher DC than its dual-cure counterpart. Higher DC in light-cure resin cements even beneath thicker and opaquer ceramics can be justified

by two major characteristics: light-cure resin cements usually include more fillers on their composition than dual-cure resin cements, increasing mechanical properties; and, photopolymerization reaction of light-cure composites probably generate high availability of free radicals, which can supply an efficient chain propagation during autoacceleration step in dimethacrylate-based resin cements (eg: Bis-EMA, Bis-GMA, UDMA, D3MA and TEGDMA).[23] This light-cure DC characteristic was also pointed out in the literature,[20,35,36] and some studies have indicated that light-cure resin cements can be used not just in thin anterior veneers but also in thicker posterior crowns.[4,21,50] However, to achieve those favorable properties of light-cure resin cements, manufacturer recommendations should be followed with a proper photopolymerization protocol.[16]

The findings in this research for the superior behavior of Variolink LC can be justified by ceramic light transmittance that let enough light pass through and photosensitize Ivocerin and by the chemical characteristics of Ivocerin. It is already known that the incorporation of Ivocerin in the composition of experimental resin cements leads to increased DC and depth of cure, and decreased yellowing; thus, it is indicated as a substitute for CQ.[42,44,45] Other studies comparing Variolink LC (Ivocerin) and NX3 LC also reported significantly higher DC for Variolink LC.[25,26,46]

The characteristics of Ivocerin favors DC, color stability, and decreases solubility and cytotoxicity.[7,25,26] Evidences indicates that other type I photoinitiators, such as TPO and BAPO, may have significantly reduced DC because they rely much more on the violet spectrum (380 to 420 nm) than on blue light (450 to 495 nm).[43,44] On the other hand, Ivocerin absorbs light in both violet and blue ranges of the spectrum, ensuring optimal polymerization.[21,22] As the wavelength of the violet spectrum is shorter than that of blue light, it can be easily scattered by the thickness and translucency of the indirect restoration because of the Rayleigh scattering phenomenon: the shorter the wavelength, the more the light scatters.[21,22,41]

There were not enough reports regarding the composition and mechanism of the REDOX system (Kerr Corp.) present in NX3 LC and Dual, and some authors reported a lack of information provided by the manufacturer.[26,36,40] Studies have reported that NX3 LC and Dual have higher DC values when compared to cements based on QC.[20,25,26,40] Although resin cements use different photoinitiators, that difference in DC can also be justified by the monomer matrix, NX3 LC and Dual are based on Bis-GMA monomers (DC from 39% to near 75%), and Variolink LC is based on UDMA (DC up to 75%).[30,31,33,34] Likewise, those findings agree with the present study, in which Variolink LC obtained mean DC values higher than NX3 LC and Dual.

NX3 Dual presented a significantly lower DC than light-cured resin cements. It is reported that the dual characteristic of resin cements favors DC since the self-and light-curing reactions might generate more free radicals.[9,20,34,38,49] However, the opposite is also observed, as the autopolymerization components of dual-cure resin cements are insufficient to a proper conversion.[16,26,49] Consequently, to achieve an optimal DC, manufacturers suggest an ideal self-cure time before light exposure.[26,49] Some authors report that the self-cure component of dual cements reduces shrinkage stress, but it does not increase DC and may take more than 5 minutes to polymerize.[27,39,60] Based on these statements and on the lack of instructions from the manufacturer (Kerr Corp.) about the self-cure time for NX3 Dual, studies light-cured the NX3 Dual immediately after placing the indirect restoration.[20,36] Despite the methodology used in previous studies[20,36] and the present one, immediate light exposure of dual resin cements can delay or inhibit that self-cure reaction, directly affecting the DC.[10,20,27,29,39,40] Therefore, such inhibition may have negatively influenced DC results of NX3 Dual reported in the present study, mainly due to the absence of self-cure time (1 to 5 minutes).[20,26,49]

Although some studies suggest that the DC is higher when the light irradiance is above 3200 mW/cm,[1,5,7] the research by Faria-e-Silva & Pfeifer[1] reported higher DCs from a polywave LED lasting 20 s (Standard - 1000 mW/cm$^2$) than 3 s (Xtra power - 3200 mW/cm$^2$), through ceramic thicknesses of 0.5, 1.0 and 2.0 mm. The study reported that irradiance of 3200 mW/cm$^2$ for a short period (3 s) delivered lower levels of light energy (J/cm$^2$) to resin cement; then, light transmittance through ceramic was insufficient to convert a light-cure resin cement.[1] Therefore, the polywave LCU irradiance used in the present research at standard power for 20 s (1186.3 ± 5.5 mW/cm$^2$) was adequate for resin cements to convert properly. Variolink LC and NX3 LC reached DC values that agree with what has been reported in other studies, for the same thickness and ceramic translucency.[22,25,26,48] A study by Alkhudhairy *et al.*[26] obtained higher NX3 LC DC values (75.9%) for 1 mm-thick ceramics than in the present study (51.7%). It suggests that NX3 Light needs higher irradiance, more light transmittance energy, and/or more light-curing time, since authors[26] used an LCU with 2300 mW/cm$^2$ of irradiance for 40 s.

Overall, the influence of thickness and translucencies on the DC could affect mechanical and bond adhesion properties.[44] Moreover, Variolink LC with type I photoinitiators, based on benzoyl germanium (Ivocerin), had high DC even beneath thicker and opaquer ceramic discs. However, a higher DC cannot be optimal, and is also related to increased polymerization shrinkage, elastic modulus, and material hardness.[8,49,53]

Further experimental studies are needed to evaluate bond strength and stability, shrinkage stress, and other mechanical properties of Variolink LC, NX3 LC, and Dual. Then, as a limitation of an *in vitro* study, clinical studies are suggested to assess in vivo the integrity and longevity of indirect restorations cemented with those resin cements.

## CONCLUSION

In the conditions of the present *in vitro* study, it was concluded that increasing ceramic thickness reduced the DC of all resin cements. However, only NX3 Dual differed significantly (HT

1.0 and HT 1.5 mm). Among all groups, the DC also decreased when opacity increased, with a significant difference in the 0.3 mm-thick MO translucency that negatively affected the DC of Variolink LC. Comparing light- and dual-cure resin cements, Variolink LC (Ivocerin) achieved significantly superior performance beneath thicker and more opaque ceramics than NX3 LC and NX3 Dual. NX3 LC (REDOX) reached the expected DC > 50% without significant differences. NX3 Dual, based on Bis-GMA, did not achieve the ideal DC > 50% in all groups.

## ACKNOWLEDGEMENTS

The authors are grateful to João Rangel and the Fuel Laboratory (LAC-UFPE) for FTIR analysis, to Junior Lima for his work with the ceramic discs, and to Jansen Campos for his contribution with statistics.

## FUNDING

SL had an MD fellowship supported by CAPES, Brazil (DS-#2020).

## REFERENCES

1. Faria-E-Silva, A.L. and Pfeifer, C.S. Effectiveness of high-power LEDs to polymerize resin cements through ceramics: An *in vitro study*. *J Prosthet Dent*. 2017; **118**:631-636.
2. Mendonça, L.M., Ramalho, I.S., Lima, L., Pires, L.A., Pegoraro, T.A. and Pegoraro, L.F. Influence of the composition and shades of ceramics on light transmission and degree of conversion of dual-cured resin cements. *J Appl Oral Sci*. 2019; **27**:e20180351.
3. Runnacles, P., Correr, G.M., Baratto Filho, F., Gonzaga, C.C. and Furuse, A.Y. Degree of conversion of a resin cement light-cured through ceramic veneers of different thicknesses and types. *Braz Dent J*. 2014; **25**:38-42.
4. de Jesus, R.H., Quirino, A.S., Salgado, V., Cavalcante, L.M., Palin, W.M. and Schneider, L.F. Does ceramic translucency affect the degree of conversion of luting agents? *Appl Adhes Sci*. 2020; **8**:4
5. Martins, F.V., Vasques, W.F. and Fonseca, E.M. How the Variations of the Thickness in Ceramic Restorations of Lithium Disilicate and the Use of Different Photopolymerizers Influence the Degree of Conversion of the Resin Cements: A Systematic Review and Meta-Analysis. *J Prosthodont*. 2019; **28**:e395-e403.
6. David-Pérez, M., Ramírez-Suárez, J.P., Latorre-Correa, F. and Agudelo-Suárez, A.A. Degree of conversion of resin-cements (light-cured/dual-cured) under different thicknesses of vitreous ceramics: systematic review. *J Prosthodont Res*. 2022; **66**:385-394.
7. Li, Q. Effects of Luting Composites on the Resultant Colors of Ceramic Veneers to Intended Shade Tab. *J Prosthodont*. 2019; **28**:327-331.
8. Lee, I.B., An, W., Chang, J. and Um, C.M. Influence of ceramic thickness and curing mode on the polymerization shrinkage kinetics of dual-cured resin cements. *Dent Mater*. 2008; **24**:1141-1147.
9. Souza, E.J., Borges, B.C., Oliveira, D.C., Brandt, W.C., Hirata, R., Silva, E.J., *et al*. Influence of the curing mode on the degree of conversion of a dual-cured self-adhesive resin luting cement beneath ceramic. *Acta Odontol Scand*. 2013; **71**:444-448.
10. De Souza, G., Braga, R.R., Cesar, P.F. and Lopes, G.C. Correlation between clinical performance and degree of conversion of resin cements: a literature review. *J Appl Oral Sci*. 2015; **23**:358-368.
11. Mendonca, L.M., Ramalho, I.S., Lima, L., Pires, L.A., Pegoraro, T.A. and Pegoraro, L.F. Influence of the composition and shades of ceramics on light transmission and degree of conversion of dual-cured resin cements. *J Appl Oral Sci*. 2019; **27**:e20180351.
12. Koch, A., Kroeger, M., Hartung, M., Manetsberger, I., Hiller, K.A., Schmalz, G., *et al*. Influence of ceramic translucency on curing efficacy of different light-curing units. *J Adhes Dent*. 2007; **9**:449-462.
13. Blumentritt, F.B., Cancian, G., Saporiti, J.M., de Holanda, T.A., Barbon, F.J. and Boscato, N. Influence of feldspar ceramic thickness on the properties of resin cements and restorative set. *Eur J Oral Sci*. 2021; **129**:e12765.
14. Pacheco, R.R., Carvalho, A.O., Andre, C.B., Ayres, A.P.A., de Sa, R.B.C., Dias, T.M., *et al*. Effect of indirect restorative material and thickness on light transmission at different wavelengths. *J Prosthodon Res*. 2019; **63**:232-238.
15. Rueggeberg, F.A., Giannini, M., Arrais, C.A.G. and Price, R.B.T. Light curing in dentistry and clinical implications: a literature review. *Braz Oral Res*. 2017; **31**:e61.
16. Hardy, C.M.F., Bebelman, S., Leloup, G., Hadis, M.A., Palin, W.M. and Leprince, J.G. Investigating the limits of resin-based luting composite photopolymerization through various thicknesses of indirect restorative materials. *Dent Mater*. 2018; **34**:1278-1288.
17. Ilie, N. Impact of light transmittance mode on polymerisation kinetics in bulk-fill resin-based composites. *J Dent*. 2017; **63**:51-59.
18. Ilie, N. and Hickel, R. Correlation between ceramics translucency and polymerization efficiency through ceramics. *Dent Mater*. 2008; **24**:908-914.
19. Peña, C., Riva, E., Schutz, N., Tarín-Arzaga, L., Martínez-Cordero, H., Bove, V., *et al*. Different outcomes for transplant-eligible newly diagnosed multiple myeloma patients in Latin America according to the public versus private management: a GELAMM study. *Leuk Lymphoma*. 2020; **61**:3112-3119.
20. Scotti, N., Comba, A., Cadenaro, M., Fontanive, L., Breschi, L., Monaco, C., *et al*. Effect of Lithium Disilicate Veneers of Different Thickness on the Degree of Conversion and Microhardness of a Light-Curing and a Dual-Curing Cement. *Int J Prosthodont*. 2016; **29**:384-388.
21. Mazão, J.D., Braga, S., Brangança, G., Zancopé, K., Price, R.B. and Soares, C.J. Effect of Ceramic Thickness on Light Attenuation, Degree of Conversion, Knoop Hardness, and Elastic Modulus of Four Luting Resins. *Oper Dent*. 2023; **48**:226-235.
22. Braga, S.S.L., Price, R.B., Juckes, S.M., Sullivan, B. and Soares, C.J. Effect of the violet light from polywave light-polymerizing units on two resin cements that use different photoinitiators. *J Prosthet Dent*. 2022; **31**:S0022-3913
23. Queiroz, M.E., Maluly-Proni, A.T., Tsutsumi, M.S.C., Dallazen, E., de Castro-Hoshino, L.V., de Souza, M., *et al*. Influence of thickness and degree of opacity of lithium disilicate on the degree of conversion and bond strength of resin cements. *J Mech Behav Biomed Mater*. 2023; **143**:105934.
24. Peixoto, R.T., Paulinelli, V.M., Sander, H.H., Lanza, M.D., Cury, L.A. and Poletto, L.T. Light transmission through porcelain. *Dent Mater*. 2007; **23**:1363-1368.
25. Alkhudhairy, F., Vohra, F., Naseem, M., Owais, M.M., Amer, A.H.B. and Almutairi, K.B. Color stability and degree of conversion of a novel dibenzoyl germanium derivative containing photo-polymerized resin luting cement. *J Appl Biomater Funct Mater*. 2020; **18**:2280800020917326.
26. Alkhudhairy, F., AlKheraif, A., Naseem, M., Khan, R. and Vohra, F. Degree of conversion and depth of cure of Ivocerin containing photo-polymerized resin luting cement in comparison to conventional luting agents. *Pak J Med Sci*. 2018; **34**:253-259.

27. Faria-e-Silva, A.L., Piva, E., Lima, G.S., Boaro, L.C., Braga, R.R. and Martins, L.R. Effect of immediate and delayed light activation on the mechanical properties and degree of conversion in dual-cured resin cements. *J Oral Sci*. 2012; **54**:261-266.
28. Zhang, L., Luo, X.P. and Tan, R.X. Effect of Light-Cured Resin Cement Application on Translucency of Ceramic Veneers and Light Transmission of LED Polymerization Units. *J Prosthodont*. 2019; **28**:e376-e382.
29. Faria-e-Silva, A., Boaro, L., Braga, R., Piva, E., Arias, V. and Martins, L. Effect of immediate or delayed light activation on curing kinetics and shrinkage stress of dual-cure resin cements. *Oper Dent*. 2011; **36**:196-204.
30. Kim, M.J., Kim, K.H., Kim, Y.K. and Kwon, T.Y. Degree of conversion of two dual-cured resin cements light-irradiated through zirconia ceramic disks. *J Adv Prosthodont*. 2013; **5**:464-470.
31. Sideridou, I., Tserki, V. and Papanastasiou, G. Effect of chemical structure on degree of conversion in light-cured dimethacrylate-based dental resins. *Biomaterials*. 2002; **23**:1819-1829.
32. Kalachandra, S., Sankarapandian, M., Shobha, H.K., Taylor, D.F. and McGrath, J.E. Influence of hydrogen bonding on properties of BIS-GMA analogues. *J Mater Sci Mater Med*. 1997; **8**:283-286.
33. Floyd, C.J. and Dickens, S.H. Network structure of Bis-GMA- and UDMA-based resin systems. *Dent Mater*. 2006; **22**:1143-1149.
34. Walters, N.J., Xia, W., Salih, V., Ashley, P.F. and Young, A.M. Poly(propylene glycol) and urethane dimethacrylates improve conversion of dental composites and reveal complexity of cytocompatibility testing. *Dent Mater*. 2016; **32**:264-277.
35. Calgaro, P.A., Furuse, A.Y., Correr, G.M., Ornaghi, B.P. and Gonzaga, C.C. Influence of the interposition of ceramic spacers on the degree of conversion and the hardness of resin cements. *Braz Oral Res*. 2013; **27**:403-409.
36. Cho, S.H., Lopez, A., Berzins, D.W., Prasad, S. and Ahn, K.W. Effect of Different Thicknesses of Pressable Ceramic Veneers on Polymerization of Light-cured and Dual-cured Resin Cements. *J Contemp Dent Pract*. 2015; **16**:347-352.
37. Meng, X., Yoshida, K. and Atsuta, M. Influence of ceramic thickness on mechanical properties and polymer structure of dual-cured resin luting agents. *Dent Mater*. 2008; **24**:594-599.
38. Aguiar, T.R., Di Francescantonio, M., Arrais, C.A., Ambrosano, G.M., Davanzo, C. and Giannini, M. Influence of curing mode and time on degree of conversion of one conventional and two self-adhesive resin cements. *Oper Dent*. 2010; **35**:295-299.
39. Pereira, S.G., Fulgêncio, R., Nunes, T.G., Toledano, M., Osorio, R. and Carvalho, R.M. Effect of curing protocol on the polymerization of dual-cured resin cements. *Dent Mater*. 2010; **26**:710-718.
40. Aldhafyan, M., Silikas, N. and Watts, D.C. Influence of curing modes on conversion and shrinkage of dual-cure resin-cements. *Dent Mater*. 2022; **38**:194-203.
41. Rizzante, F.A.P., Locatelli, P.M., Porto, T.S., Borges, A.F.S., Mondelli, R.F.L. and Ishikiriama, S.K. Physico-mechanical properties of resin cement light cured through different ceramic spacers. *J Mech Behav Biomed Mater*. 2018; **85**:170-174.
42. Moszner, N., Fischer, U.K., Ganster, B., Liska, R. and Rheinberger, V. Benzoyl germanium derivatives as novel visible light photoinitiators for dental materials. *Dent Mater*. 2008; **24**:901-907.
43. Favarão, J., Oliveira, D., Zanini, M.M., Rocha, M.G., Correr-Sobrinho, L. and Sinhoreti, M. Effect of curing-light attenuation on color stability and physical and chemical properties of resin cements containing different photoinitiators. *J Mech Behav Biomed Mater*. 2021; **113**:104110.
44. Castellanos, M., Delgado, A.J., Sinhoreti, M.A.C., de Oliveira, D.C.R.S., Abdulhameed, N., Geraldeli, S., *et al*. Effect of Thickness of Ceramic Veneers on Color Stability and Bond Strength of Resin Luting Cements Containing Alternative Photoinitiators. *J Adhes Dent*. 2019; **21**:67-76.
45. Delgado, A.J., Castellanos, E.M., Sinhoreti, M., Oliveira, D.C., Abdulhameed, N., Geraldeli, S., *et al*. The Use of Different Photoinitiator Systems in Photopolymerizing Resin Cements Through Ceramic Veneers. *Oper Dent*. 2019; **44**:396-404.
46. Ramos, R.Q., Moraes, R.R. and Lopes, G.C. Effect of LED Light-Curing Spectral Emission Profile on Light-Cured Resin Cement Degree of Conversion. *Oper Dent*. 2021; **46**:63-74.
47. Jerri, B.A. Evaluate polymer degree of conversion of bulk-fill composite restoration. *IOSR Journal of Dental and Medical Sciences*. 2015; **14**:75-79.
48. Bragança, G.F., Vianna, A.S., Neves, F.D., Price, R.B. and Soares, C.J. Effect of exposure time and moving the curing light on the degree of conversion and Knoop microhardness of light-cured resin cements. *Dent Mater*. 2020; **36**:e340-e351.
49. Novais, V.R., Raposo, L.H., Miranda, R.R., Lopes, C.C., Simamoto, P.C. and Soares, C.J. Degree of conversion and bond strength of resin-cements to feldspathic ceramic using different curing modes. *J Appl Oral Sci*. 2017; **25**:61-68.
50. Liporoni, P.C., Ponce, A.C., de Freitas, M.R., Zanatta, R.F., Pereira, M.C. and Catelan, A. Influence of thickness and translucency of lithium disilicate ceramic on degree of conversion of resinous materials. *J Clin Exp Dent*. 2020; **12**:e745-e748.
51. Babaier, R., Haider, J., Silikas, N. and Watts, D.C. Effect of CAD/CAM aesthetic material thickness and translucency on the polymerisation of light- and dual-cured resin cements. *Dent Mater*. 2022; **38**:2073-2083.
52. Shono, N.N., Elhejazi, A., Maawadh, A. and Al Nahedh, H. Effect of Translucency and Curing Mode of Four CAD/CAM Materials on Polymerization Efficiency of Light and Dual Cure Resin Cements. *Eur J Prosthodont Restor Dent*. 2022; **30**:230-238.
53. Lopes, Ce.C., Rodrigues, R.B., Silva, A.L., Simamoto Júnior, P.C., Soares, C.J. and Novais, V.R. Degree of Conversion and Mechanical Properties of Resin Cements Cured Through Different All-Ceramic Systems. *Braz Dent J*. 2015; **26**:484-489.
54. Ribeiro, R.A.dO., Lima, F.F.dC., Lima, I.M., Nascimento, A.B.L.d. and Teixeira, H.M. Avaliação da intensidade de luz e da manutenção dos aparelhos fotopolimerizadores utilizados em clínicas odontológicas da cidade do Recife-PE. *Revista de Odontologia da UNESP*. 2016; **45**:351-355.
55. Oh, S., Shin, S.M., Kim, H.J., Paek, J., Kim, S.J., Yoon, T.H., *et al*. Influence of glass-based dental ceramic type and thickness with identical shade on the light transmittance and the degree of conversion of resin cement. *Int J Oral Sci*. 2018; **10**:5.
56. Jafari, Z., Alaghehmand, H., Samani, Y., Mahdian, M. and Khafri, S. Light transmittance of CAD/CAM ceramics with different shades and thicknesses and microhardness of the underlying light-cured resin cement. *Restor Dent Endod*. 2018; **43**:e27.
57. Bueno, A.L., Arrais, C.A., Jorge, A.C., Reis, A.F. and Amaral, C.M. Light-activation through indirect ceramic restorations: does the overexposure compensate for the attenuation in light intensity during resin cement polymerization? *J Appl Oral Sci*. 2011; **19**:22-27.
58. Flury, S., Lussi, A., Hickel, R. and Ilie, N. Light curing through glass ceramics with a second- and a third-generation LED curing unit: effect of curing mode on the degree of conversion of dual-curing resin cements. *Clin Oral Investig*. 2013; **17**:2127-2137.
59. Kilinc, E., Antonson, S.A., Hardigan, P.C. and Kesercioglu, A. The effect of ceramic restoration shade and thickness on the polymerization of light- and dual-cure resin cements. *Oper Dent*. 2011; **36**:661-669.
60. Hofmann, N., Papsthart, G., Hugo, B. and Klaiber, B. Comparison of photo-activation versus chemical or dual-curing of resin-based luting cements regarding flexural strength, modulus and surface hardness. *J Oral Rehabil*. 2001; **28**:1022-1028.