Original Article

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Effect of translucency and thickness of lithium disilicate ceramic on light transmission and composite cement polymerization

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Objective: To evaluate the effect of translucency and thickness of lithium disilicate ceramic on the light irradiance (LI) and the degree of conversion (DC) of a dual-cure and a light-cure composite cement under two LED light-curing units (LCUs).

Materials and Methods: IPS e.max CAD discs were prepared in two translucencies (HT-A3, LT-A3) and four thicknesses (2, 3, 4, 5 mm), with no-ceramic controls. Two LED LCUs (Bluephase N G4, polywave; Elipar DeepCure-S, monowave) were used, both delivering ~1100 mW/cm² for 40 s. LI was measured with a light spectrometer (n = 2 per cell). DC of a dual-cure resin cement (Variolink Esthetic DC) and a light-cure restorative composite (Clearfil AP-X) was measured by micro-Raman spectroscopy at six time points (1 min, 5 min, 15 min, 1 h, 24 h, 1 week; n = 3 per cell). Non-parametric tests were used (α = 0.05).

Results: LI decreased with increasing ceramic thickness and lower translucency (Spearman's ρ = −0.94 to −0.98, $p \leq 0.001$) and fell below the detection limit at LT-A3 5 mm under both LCUs. DC increased over time, reaching a pooled mean of ~78% at one week; but the response depended on both cement chemistry and LCU spectrum. Variolink reached the 90% threshold in 6/8 ceramic groups under Bluephase N G4 and 5/8 under Elipar DeepCure-S, while Clearfil AP-X reached it in only 2/8 and 5/8, respectively. The worst-performing condition was Clearfil/LT-A3 5 mm (fitted plateau A = 66.27% under Elipar DeepCure-S).

Conclusion: Within the limitations of this in vitro study, lithium disilicate translucency and thickness markedly reduced LI and modulated DC in a cement- and LCU-dependent manner. Clinicians may consider a dual-cure cement combined with a polywave LCU when cementing thick or low-translucency lithium disilicate restorations.

Keywords: ceramic, composite cement, degree of conversion, light curing, light transmission, polymerization

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Introduction

All-ceramic restorations, particularly those made from lithium disilicate glass ceramic, are now commonly used in dentistry due to their excellent esthetic properties, strength and biocompatibility, as well as availability in various translucency levels [1, 2]. Achieving reliable and long-lasting indirect restorations is a major goal of restorative treatment, in which adhesive cementation plays an

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important role in enhancing the fracture strength and durability of these restorations [3, 4]. Recently, there has been an increasing trend toward the use of restorative resin-based composites as solely light-curable cements for adhesive luting owing to advantages such as on-demand setting and higher consistency [5, 6]. These restorative composites have also been reported to provide better mechanical properties than conventional resin cements [3-5]. One of the key factors affecting the long-term survival of indirect restorations is the success of resin cement polymerization, which is reflected by its degree of conversion (DC) [7]. Inadequate DC may lead to marginal leakage, debonding, decreased mechanical properties, faster degradation, and an increased risk of interfacial fracture [7]. Marginal defects are also associated with a higher risk of secondary caries and endodontic complications. Since the amount of light reaching the luting material is influenced by the optical properties of the overlying ceramic, the translucency and thickness of ceramic restorations may affect the polymerization efficiency of resin-based cements [4, 8].

Although previous studies have examined light irradiance (LI) attenuation through ceramic or the resulting DC of polymerized cements, the combined effect of ceramic translucency, thickness, cement type, and light-curing unit (LCU) spectral profile on the polymerization of composite cements has not been examined together within a single study. Therefore, this exploratory in vitro study evaluated the effect of translucency and thickness of lithium disilicate ceramic on the LI delivered by two LCUs and on the DC of two composite cements differing in curing chemistry. Two null hypotheses were tested: (H_{01}) ceramic translucency, thickness, and LCU type would not affect the LI delivered to the cement; and (H_{02}) ceramic translucency, thickness, cement type, LCU type, and post-irradiation time would not affect cement DC.

Materials and Methods

Ceramic discs preparation

Lithium disilicate CAD/CAM blocks (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein), classified according to ISO 6872:2015, were prepared as rectangular discs (12 × 14 mm) in two translucencies (HT-A3 and LT-A3) and four thicknesses (2, 3, 4, and 5 mm). Two specimens were prepared for each thickness and translucency combination (n = 2), totaling 16 ceramic specimens. The blocks were sectioned using a precision cutting machine (Accutom-100; Struers, Ballerup, Denmark) with a diamond cut-off wheel (300 µm, M1D10, Struers) under continuous water cooling at a feed speed of 0.05 mm/s and a wheel speed of 4000 rpm. To simulate clinical milling roughness (approximating that produced by a 64-µm grit milling bur), the surfaces were ground with 220-grit silicon-carbide (SiC) paper (Buehler, Lake Bluff, IL, USA) under water cooling on a polishing machine (RotoForce-4, Struers). The specimens were then crystallized in a furnace (Programat P300, Ivoclar Vivadent) according to the manufacturer's instructions and subsequently glazed (IPS e.max CAD Crystall./Glaze Paste, Ivoclar Vivadent). The final thickness of each specimen was verified using a digital vernier caliper (CD-6" SX; Mitutoyo, Kanagawa, Japan).

Light irradiance (LI) measurement

Light irradiance (LI) was measured using two light-emitting diode (LED) light-curing units: a polywave LCU (Bluephase N G4, Ivoclar Vivadent, Schaan, Liechtenstein) and a monowave LCU (Elipar DeepCure-S, 3M Oral Care, St. Paul, MN, USA). Both units were operated in high-power mode for 40 s. Transmitted LI was recorded across a wavelength range of 360–540 nm using a calibrated spectrometer (CheckMARC, BlueLight

Analytics Inc., Halifax, Canada) integrated with the BlueLight Analytics software. For each measurement, the LCU tip was positioned perpendicular to and in direct contact with the ceramic surface. For each ceramic specimen, three within-specimen replicate measurements were recorded and averaged to yield one value per specimen (n = 2 specimens per translucency × thickness group). For the no-ceramic control, three independent measurements were recorded (n = 3). The spectrometer had a minimum detectable irradiance of 10 mW/cm²; values below this limit were reported as < 10 mW/cm² and excluded from inferential analyses.

Degree of conversion (DC) measurement

Following LI measurement, the ceramic specimens were transferred to evaluate the degree of conversion (DC) of the resin-based cements by micro-Raman spectroscopy (LabRAM HR Evolution, HORIBA Scientific, Kyoto, Japan), according to ISO 4049:2019. To simulate the clinical luting procedure for indirect restorations, two cements were tested: a dual-cure resin cement (Variolink Esthetic DC, Ivoclar Vivadent, Schaan, Liechtenstein) and a light-cure restorative composite (Clearfil AP-X, Kuraray Noritake Dental Inc., Tokyo, Japan). The cements were placed on a 1-mm-thick transparent glass slide and compressed to a standardized 100-µm film thickness using a 100-µm-thick cover glass. Variolink Esthetic DC was hand-mixed in a 1:1 base-to-catalyst ratio with a plastic spatula for 10 s. The composite specimens were approximately 5 mm in diameter, with luting space thickness standardized at 100 µm by two additional 100-µm-thick cover glasses placed on either side of the cement (n = 3 per cell).

Specimens were either covered with one of

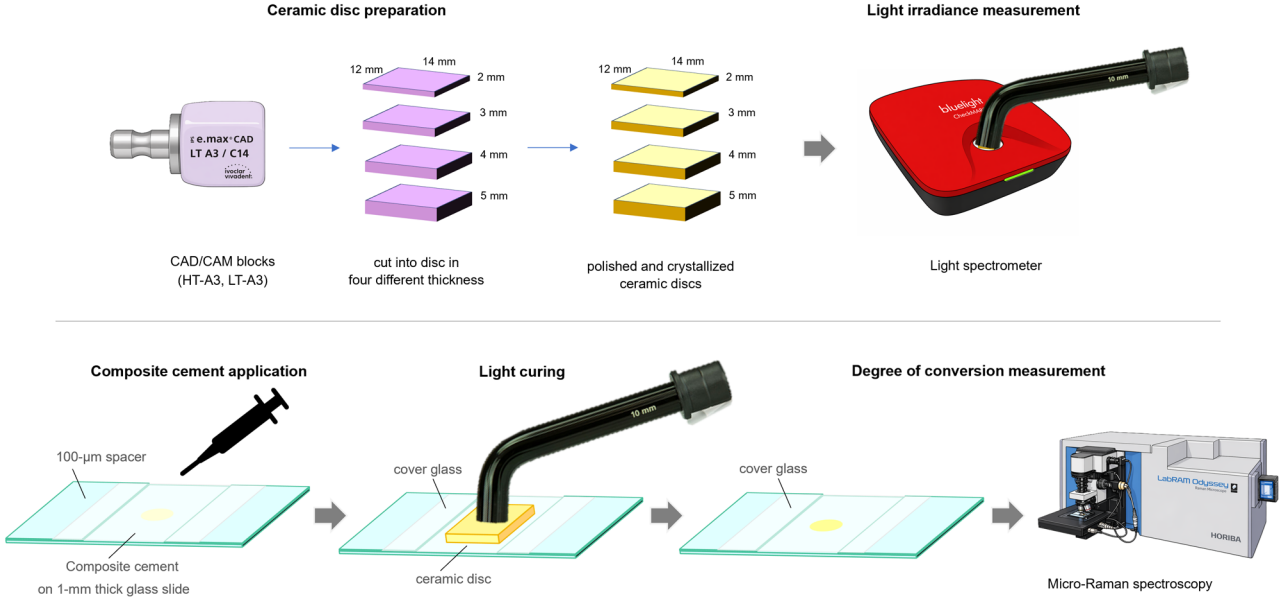


Figure 1 Schematic representation of specimen preparation and measurement procedures. **Top row:** ceramic disc preparation (sectioning, polishing, crystallization, glazing) and light irradiance (LI) measurement using a light spectrometer. **Bottom row:** composite cement application, light-curing with two LCUs, and degree of conversion (DC) measurement by micro-Raman spectroscopy.

the prepared ceramic discs or left uncovered (control group). Both LCUs (Bluephase N G4 and Elipar DeepCure-S) were perpendicularly positioned on top, in direct contact with the ceramic disc or the top cover glass (control group), then light-cured for 40 s. The study setup is summarized in Figure 1.

Micro-Raman spectra were recorded at the center of each specimen at six time points (1, 5, and 15 min; 1 and 24 h; and 1 week) post-curing, using the following parameters: 785-nm diode laser, 600 grooves/mm diffraction grating, and a 100× objective, with a spectral integration time of 50 s. All specimens were kept covered with glass slides, dry, and dark at 37°C on a hot plate throughout the measurement period. The degree of conversion (DC) was calculated from the decrease in the aliphatic C=C peak at 1638 cm^{-1} between uncured and cured spectra, normalized to a stable reference peak, according to the following formula:

$$DC\% = \left(1 - \frac{C_{aliphatic} / C_{reference}}{U_{aliphatic} / U_{reference}}\right) \times 100\ (\%)$$

The reference peak was the C–H peak at 1455 cm^{-1} for Variolink Esthetic DC and the aromatic C=C peak at 1608 cm^{-1} for Clearfil AP-X. After baseline correction, the fraction of remaining C=C double bonds in each spectrum was determined by comparing the maximum heights of the aliphatic and reference peaks using LabSpec 6 software (HORIBA Scientific).

Statistical analysis

All data were analyzed using SPSS Statistics version 29 (IBM Corp., Armonk, NY, USA), with $\alpha = 0.05$. Due to the small sample size (n = 2 per ceramic cell + n = 3 for the no-ceramic control for LI; n = 3 per cell for DC), non-parametric tests were used for all comparisons.

For LI, the Wilcoxon signed-rank test compared paired Bluephase vs. Elipar readings across all ceramic specimens; the Mann–Whitney U test compared HT-A3 vs. LT-A3 pooled across thicknesses; the Kruskal–Wallis H test compared ceramic groups within each LCU, followed by Dunn's post-hoc test with Holm correction for pairwise comparisons; and Spearman's ρ quantified the relationship between thickness and LI within each translucency × LCU combination. Values below the spectrometer's 10 mW/cm^2 detection limit were reported descriptively and excluded from inferential analyses.

For DC, the Friedman test assessed the within-subject effect of time for each experimental cell. The Kruskal–Wallis H test compared ceramic groups at one week within each cement × LCU subset, followed by Dunn's post-hoc test with Holm correction for pairwise comparisons. The Mann–Whitney U test compared HT-A3 vs. LT-A3 at each time point; the Wilcoxon signed-rank test compared LCUs within each cement type; and Spearman's ρ quantified the correlation between ceramic thickness and DC within each experimental subset. Given the limited sample size, all inferential analyses were considered exploratory.

Results

Light irradiance (LI) measurements

The LI measurements are presented in Table 1. Without the interposition of any ceramic disc, Bluephase N G4 (1134.67 ± 1.53 mW/cm^2) and Elipar DeepCure-S (1137.33 ± 1.53 mW/cm^2) delivered comparable baseline irradiances. Across all ceramic groups, LI decreased progressively with increasing ceramic thickness and was consistently lower for LT-A3 than for HT-A3 at matching thicknesses. At the largest

Table 1 Light irradiance (mean ± SD; mW/cm²) delivered by two light-curing units through ceramic discs.

Group	Thickness	Bluephase N G4 (mW/cm²)	Elipar DeepCure-S (mW/cm²)
Control	-	1134.67 ± 1.53[a]	1137.33 ± 1.53[a]
HT-A3 ceramic			
HT-A3	2 mm	242.50 ± 3.54[ab]	260.50 ± 0.24[ab]
HT-A3	3 mm	143.33 ± 2.36[ab]	155.00 ± 0.00[ab]
HT-A3	4 mm	88.83 ± 0.24[ab]	98.17 ± 0.24[ab]
HT-A3	5 mm	51.83 ± 0.24[b]	58.00 ± 1.41[ab]
Spearman's ρ (thickness × LI)		*ρ = −0.976 (p < 0.001)*	*ρ = −0.982 (p < 0.001)*
LT-A3 ceramic			
LT-A3	2 mm	119.50 ± 4.01[ab]	127.67 ± 1.89[ab]
LT-A3	3 mm	66.33 ± 1.41[ab]	72.33 ± 1.41[ab]
LT-A3	4 mm	< 10 †	30.33 ± 0.47[b]
LT-A3	5 mm	< 10 †	< 10 †
Spearman's ρ (thickness × LI)		*ρ = −0.936 (p = 0.001)*	ρ = −0.982 (p < 0.001)

n = 3 for the control (no ceramic), n = 2 for each ceramic group (each value is the average of three within-specimen replicates). Different superscript letters within the same column indicate statistically significant differences between ceramic groups (Dunn's post-hoc test following Kruskal–Wallis with Holm correction, $p < 0.05$). With the limited statistical power of n = 2 per ceramic group, most pairwise comparisons did not reach significance after Holm correction. † Below the spectrometer's 10 mW/cm² lower limit of detection; excluded from inferential tests involving the affected cells.

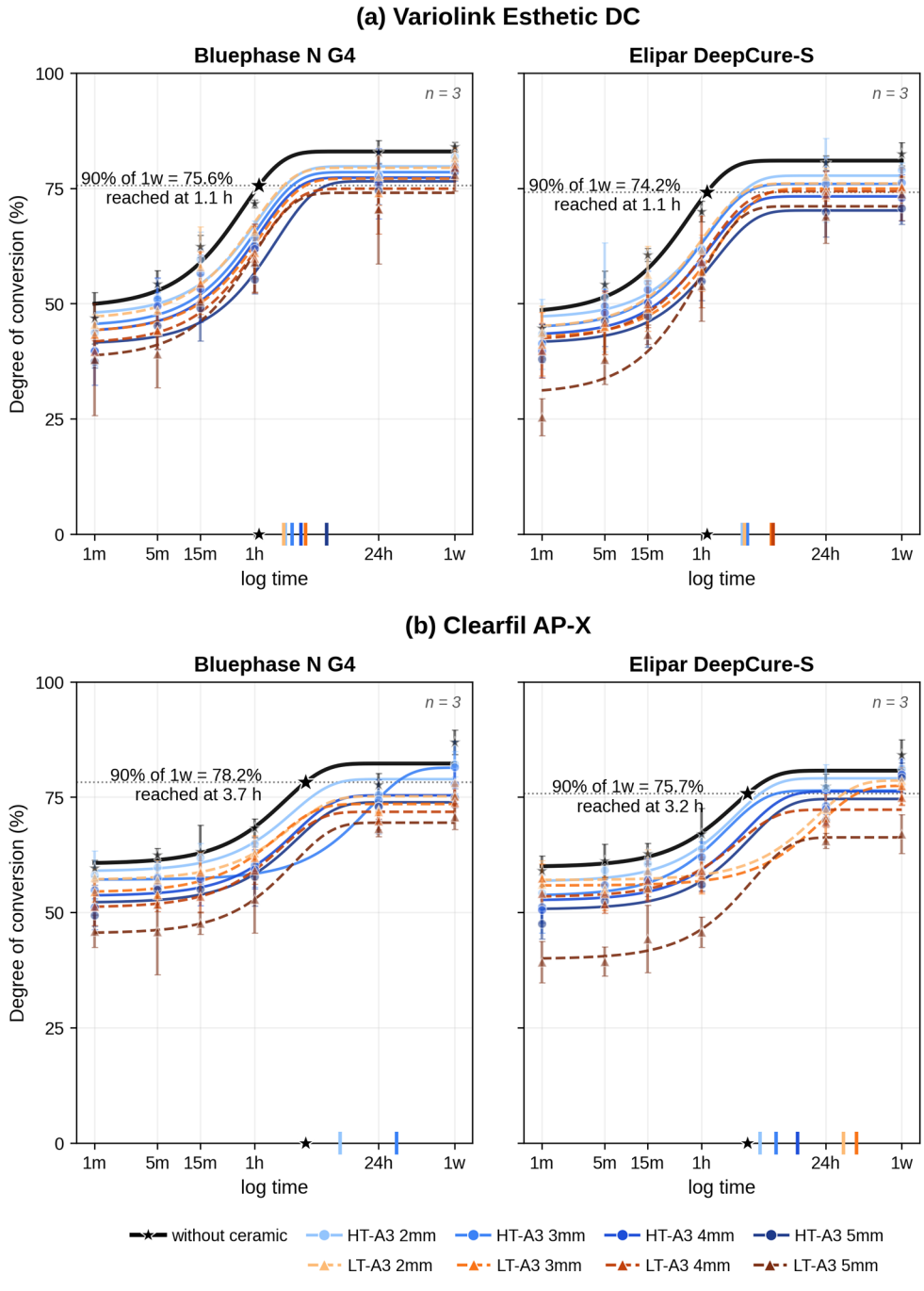
LT-A3 thicknesses, LI fell to or below the 10 mW/cm² detection limit of the spectrometer: at 4 mm, only the Elipar DeepCure-S unit produced a detectable reading (30.33 ± 0.47 mW/cm²), and at 5 mm neither LCU delivered a detectable LI.

Pooled across all ceramic groups, Elipar DeepCure-S delivered significantly higher LI than Bluephase N G4 (Wilcoxon signed-rank, $p < 0.001$). HT-A3 transmitted significantly more light than LT-A3 under both LCUs (Mann–Whitney U, $p = 0.039$ for Bluephase; $p = 0.040$ for Elipar). Within each translucency × LCU combination, LI decreased progressively with increasing ceramic thickness (Spearman's ρ = –0.94 to –0.98, all $p \leq 0.001$).

Degree of conversion (DC) measurements

The measured DC for two composite cements is graphically presented in Figure 2. DC significantly increased with time for all experimental groups (Friedman test, $p < 0.05$ in all cells), rising from approximately 41–53 % at 1 min to a pooled mean of ~78% at one week (group means ranged from ~67% to ~87%).

For Variolink Esthetic DC, a dual-cure resin cement, the 1-min DC was 40.62 ± 6.29% but increased gradually; pooled DC reached 61.09 ± 6.09% at 1 h, 75.18 ± 5.75% at 24 h, and 77.98 ± 4.27% at one week. Translucency had no significant effect at 24 h (Mann–Whitney U, $p = 0.270$) or at one week ($p = 0.975$). However, thickness was negatively correlated with 24-h DC under Elipar DeepCure-S (Spearman's ρ = –0.533, $p = 0.007$) but only borderline under Bluephase N G4 (ρ = –0.388, $p = 0.061$), and the LCU effect on 1-week DC was significant (Wilcoxon signed-rank, $p < 0.001$), with Bluephase N G4



Time to reach 90% target

Group	BP	3M
without ceramic	1.1 h	1.1 h
HT-A3 2mm	2.2 h	2.8 h
HT-A3 3mm	2.6 h	3.2 h
HT-A3 4mm	3.3 h	—
HT-A3 5mm	6.3 h	—
LT-A3 2mm	2.1 h	3.0 h
LT-A3 3mm	3.7 h	6.0 h
LT-A3 4mm	—	6.2 h
LT-A3 5mm	—	—

— = plateau below target (never reached)

Time to reach 90% target

Group	BP	3M
without ceramic	3.7 h	3.2 h
HT-A3 2mm	8.9 h	4.5 h
HT-A3 3mm	1.6 d	6.7 h
HT-A3 4mm	—	11.7 h
HT-A3 5mm	—	—
LT-A3 2mm	—	1.6 d
LT-A3 3mm	—	2.2 d
LT-A3 4mm	—	—
LT-A3 5mm	—	—

— = plateau below target (never reached)

Figure 2 Degree of conversion (DC) of **(a)** Variolink Esthetic DC and **(b)** Clearfil AP-X, light-cured through ceramic discs using two LED LCUs, at six time points. Data fitted with %DC(t) = A – B·exp(–k·t), where A = the plateau DC (%), B = amplitude from the 1-min value to the plateau, and k = rate constant (min^{-1}). Dotted horizontal line represents 90% of control DC at one week. Colored tick marks on the x-axis indicate time-to-reach-threshold; groups whose plateau remained below the threshold are shown without tick marks. Tables (right) summarize the time required for each group to reach the 90% threshold under each LCU. Error bars represent ± 1 SD (n = 3 per cell).

producing higher pooled DC (80.33%) than Elipar DeepCure-S (75.63%).

In contrast, Clearfil AP-X, a solely light-cure restorative composite, was more sensitive to ceramic interposition. The 1-min DC (52.87 ± 5.92%) was higher than that of Variolink Esthetic DC, as expected for a light-cure material. Pooled DC reached 77.96 ± 5.34% at one week, but the LT-A3 5 mm specimens under Elipar DeepCure-S had the lowest fitted plateau (A = 66.27%) — the worst-case condition in this study. Between-group differences at one week were significant under both LCUs (Kruskal–Wallis H, AP-X/Bluephase H = 20.70, p = 0.008; AP-X/Elipar H = 17.54, p = 0.025). The thickness × DC relationship at 24 h was strongly negative under both LCUs (Spearman's ρ = –0.468, p = 0.021 for Bluephase N G4; ρ = –0.641, p = 0.001 for Elipar DeepCure-S). Translucency also showed a significant effect at later time points (Mann–Whitney U, p = 0.001 at 24 h; p < 0.001 at one week), with HT-A3 groups achieving higher DC than LT-A3 groups. The paired LCU effect on AP-X was non-significant (Wilcoxon signed-rank, p = 0.279 at 24 h; p = 0.822 at one week), indicating comparable overall DC between the two LCUs for this material.

Considering an acceptable DC threshold defined as 80–90% of the maximum DC achieved by the control group, the number of groups reaching this level by one week varied between cements and LCUs. Based on a 90% threshold of the control mean, the target values were 75.6% for Variolink/Bluephase, 74.2% for Variolink/Elipar, 78.2% for AP-X/Bluephase, and 75.7% for AP-X/Elipar. By one week, Variolink Esthetic DC reached this threshold in 6/8 groups under Bluephase N G4 (LT-A3 4 mm and 5 mm failed) and 5/8 groups under Elipar DeepCure-S (HT-A3 4 mm, HT-A3 5 mm, and LT-A3 5 mm failed). In contrast, Clearfil AP-X met the threshold in only 2/8 groups under Bluephase N G4 (HT-A3 2 mm and 3 mm; all LT-A3 thicknesses and HT-A3 ≥ 4 mm failed) and 5/8 groups under Elipar DeepCure-S (HT-A3 5 mm, LT-A3 4 mm, and LT-A3 5 mm failed). The Clearfil AP-X / LT-A3 5 mm combination represented the worst-performing condition under both LCUs (fitted plateau A = 69.46% under Bluephase N G4 and 66.27% under Elipar DeepCure-S).

Discussion

Both null hypotheses were rejected. H_{01} was rejected — ceramic translucency, thickness, and LCU type all affected LI, with Elipar DeepCure-S delivering higher pooled LI than Bluephase N G4 (Wilcoxon, p < 0.001). H_{02} was partially rejected — DC depended on cement type and post-irradiation time; ceramic translucency and thickness affected Clearfil AP-X under both LCUs but affected Variolink Esthetic DC only minimally (thickness under Elipar). The LCU effect was material-specific: significant for Variolink at one week (Bluephase > Elipar, p < 0.001) but not for Clearfil. Overall, the light-cure Clearfil AP-X was most sensitive to ceramic attenuation, whereas the dual-cure Variolink was more robust under Bluephase N G4 than under Elipar DeepCure-S — confirming that polymerization through ceramic depends on the interaction of LI, LCU spectrum, and cement curing mechanism.

The study setup simulated clinical luting procedures for indirect restorations using composite cement. A standardized 100-μm film thickness was maintained using glass coverslip spacers and cement portions were covered by glass above and below throughout the whole experiment to prevent oxygen inhibition of polymerization [3, 9]. This study included Clearfil AP-X, a light-cure restorative composite, reflecting the clinical trend of using such materials for

adhesive luting [5, 9]. Restorative composites often exhibit superior wear resistance and physico-mechanical properties compared to conventional dual-cure luting agents, owing in part to their higher filler content [5].

The interposition of lithium disilicate ceramic markedly reduced the irradiance delivered to the luting area [10, 11]. LI decreased progressively with increasing ceramic thickness, consistent with Mie-type scattering at boundaries between lithium disilicate crystals and the residual glass matrix [3, 12]. The low translucency ceramic contains a higher fraction of crystalline phase, which increases scattering and reduces forward transmission [1]. This may explain why LI fell below the 10 mW/cm² detection limit at LT-A3 5 mm under both LCUs and at LT-A3 4 mm under the Bluephase N G4. This difference may be attributed to the polywave spectrum of Bluephase N G4, which contains a violet component in addition to blue; shorter violet wavelengths undergo stronger Mie scattering than blue wavelengths, reducing forward transmission through ceramic [10, 13, 14]. Values below the detection threshold were reported descriptively as < 10 mW/cm² and excluded from inferential tests involving the affected cells.

The most clinically relevant observation is that the response of DC to ceramic attenuation depended on both cement chemistry and LCU spectrum. The dual-cure Variolink Esthetic DC achieved a pooled mean DC of approximately 75% at 24 h and 78% at one week, with no significant translucency effect (Mann–Whitney, p = 0.270 at 24 h; p = 0.975 at one week) — consistent with redox co-initiation that sustains polymerization in part independently of irradiance [15-17]. Under Bluephase N G4, this chemical pathway combined with polywave irradiation — which activates alternative co-initiators such as TPO, Lucirin, or Ivocerin — enabled Variolink to reach the 90% threshold in 6/8 ceramic groups; only LT-A3 at 4 mm and 5 mm fell short. Under Elipar DeepCure-S, three groups (HT-A3 4 mm, HT-A3 5 mm, LT-A3 5 mm) failed the threshold, indicating that the chemical-curing component alone, without polywave activation, was not sufficient to compensate for severely attenuated monowave irradiation. Clearfil AP-X, lacking a chemical pathway, showed significant negative thickness–DC correlations at 24 h under both LCUs (Spearman's ρ = –0.468 under Bluephase, ρ = –0.641 under Elipar), with the worst-case LT-A3 5 mm group plateauing at A = 69.46% under Bluephase N G4 and A = 66.27% under Elipar DeepCure-S — well below the 90% threshold. The continued DC increase up to one week reflects diffusion-limited dark polymerization [16-18].

The LCU effect on DC was material- and time-dependent. For Variolink Esthetic DC, no significant LCU difference was observed at 24 h (Wilcoxon signed-rank, p = 0.546), but by one week Bluephase N G4 produced higher pooled DC than Elipar DeepCure-S (p < 0.001). This delayed divergence is consistent with polywave-driven activation of the alternative co-initiators in Variolink, providing a continued radical supply for the slower dark polymerization that proceeds between 24 h and one week [19]. For Clearfil AP-X, no significant LCU difference was observed at either 24 h (p = 0.279) or one week (p = 0.822). This is expected since AP-X contains only camphorquinone, which is activated by blue wavelengths supplied equivalently by both LCUs; the additional violet component of the polywave Bluephase N G4 has no matching photoinitiator in AP-X and therefore confers no advantage [18-21]. The limited statistical power of n = 3 per cell may also have prevented detection of small true differences.

For the 80–90% range as a criterion for adequate polymerization, the 0.80 bottom-to-top

hardness criterion was originally derived for filled composites [22], and the corresponding 0.90 DC ratio was established by Bouschlicher *et al.* [22] and reproduced by Miletic *et al.* [23]. The 90% benchmark used here — 90% of each LCU-matched control mean DC at one week — is therefore best interpreted as a comparative criterion within this study, not as an absolute clinical threshold. Within this framework, Variolink Esthetic DC was the more robust material, meeting the threshold in 11/16 ceramic conditions (6/8 under Bluephase, 5/8 under Elipar), whereas Clearfil AP-X met the threshold in only 7/16 (2/8 under Bluephase, 5/8 under Elipar), and was particularly vulnerable to low translucency or large ceramic thickness — under Bluephase N G4, all LT-A3 thicknesses failed even at 2 mm. Clinically, a dual-cure cement combined with a polywave LCU may be preferred when cementing lithium disilicate restorations of low translucency or appreciable thickness. The 5-mm condition tested here represents a worst-case boundary scenario rather than a routinely indicated clinical thickness (typical preparations: 1.0–1.5 mm) [1].

Several limitations should be considered. The small sample size (n = 2 for LI, n = 3 for DC per cell) limited statistical power, so all inferential analyses should be regarded as exploratory. These results are specific to the A3 shade, two composite cements, and a 40-s exposure protocol; generalization to other materials or settings requires caution. The spectrometer's 10 mW/cm² detection limit precluded quantification of severely attenuated groups, which were reported descriptively rather than statistically. The 100-µm cover glass may have introduced minor refractive interfaces, although this was kept constant across all groups. Ceramic surfaces were not silanated or acid-etched, as the focus was the cement interface. The use of hand-mixing for the dual-cure cement and dry storage at 37°C might yield DC values that differ from those under automixed delivery or clinically aged conditions. Future research employing larger, power-calculated sample sizes, accelerated aging (e.g., thermocycling or water storage), and a broader range of ceramic shades and materials would strengthen the clinical relevance of these findings.

Conclusion

Within the limitations of this in vitro study, lithium disilicate translucency and thickness markedly reduced light irradiance and modulated the degree of conversion in a cement- and LCU-dependent manner. The light-cure Clearfil AP-X was sensitive to ceramic attenuation, particularly at low translucency or large thickness. The dual-cure Variolink Esthetic DC was more robust, especially under the polywave Bluephase N G4, but still showed reduced DC at large LT-A3 thicknesses and at HT-A3 ≥ 4 mm under the monowave Elipar DeepCure-S. Clinicians may consider a dual-cure cement combined with a polywave LCU when cementing thick or low-translucency lithium disilicate restorations.

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