Original Article

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The effect of light curing intensity on dentin bond strength of a dual-cure resin cement polymerized under a lithium disilicate ceramic

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Objectives: To evaluate the impact of different light curing intensities on the bond strength of dual-cure resin cement under lithium disilicate ceramic.

Materials and Methods: Thirty-third molars were sectioned to expose midcoronal dentin, divided into three experimental groups with 10 specimens. Each group was bonded to truncated cone-shaped lithium disilicate ceramics using Panavia V5 dual-cure resin cement that were polymerized with 3 conditions: group 1, no light-curing, group 2, light cured with High mode (1123±4.83 mW/cm²), and with Turbo mode (1981±11.00 mW/cm²) in group 3. The light-curing for 60 seconds was used in this study. After 24 hours, the degree of conversion (DC) was measured on both primer and cement sides using a Raman spectrometer, and all bonded specimens underwent a tensile bond strength test.

Results: The uncured cement showed the lowest DC (70.88±0.55%), while light-curing significantly increased DC (High mode: 73.56±0.25%, Turbo mode: 75.94±0.61%). No significant differences were found in DC on the primer side of cement for uncured, High mode, and Turbo mode (98.91±0.04%, 98.92±0.03% to 98.93±0.03% accordingly). Mean TBS for groups 1, 2, and 3 were 5.53 MPa, 11.27 MPa, and 14.52 MPa, respectively, showing significant differences.

Conclusions: DC improved significantly with light curing on the cement side, though it did not affect the adhesive side. The tensile bond strength was enhanced with increased light curing intensity.

Keywords: ceramic, degree of conversion, dual-cure resin cement, light curing, tensile bond strength

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Introduction

One of the widely utilized dental ceramics for posterior restorations is the IPS e.max® system, a lithium disilicate-based material. This system provides exceptional aesthetics and various translucency options and demonstrates high mechanical performance [1]. This lithium disilicate-based material requires the use of a luting cement to bond to tooth structures. Resin cements provide an optimal bond with all-ceramic restorations and evenly distribute the compression force along all contact surfaces [2, 3]. Resin cements are frequently selected for luting indirect restorations owing to their superior mechanical performance relative to non-resin cements, their capacity to bond effectively to both tooth substrates and restorative materials

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with or without an adhesive system, and their improved optical properties over conventional luting agents [4-6]. However, light curing through dental ceramics is known to reduce irradiance, a consequence of ceramic opacity, which can lead to a lower degree of conversion in resin-based luting cements [7]. This reduction in conversion has been shown in both light-cure and dual-cure systems [8]. The incomplete polymerization of resin cement can lead to increased water sorption and solubility, accelerating degradation of the cement at the finish line due to acid exposure [9]. This degradation reduces the bond between the cement and the tooth or restoration [10], potentially resulting in marginal breakdown and clinical failure of the restoration through debonding, fracture, or the development of secondary caries [11]. The research question of this study was whether irradiation of the dual-cure resin cement and the increase of its degree of conversion results in an improvement of dentin bond strength.

The purpose of this study was to investigate the impact of a curing mode of an LED light-curing unit on the tensile bond strength of lithium disilicate ceramic luted with a dual-cure resin cement on dentin. Null hypotheses of this study were 1) there was no effect of curing modes and 2 mm thick ceramic on light intensity, 2) there was no effect of curing modes and 2 mm thick ceramic on degree of conversion of resin cement (primer & cement), 3) there was no effect of curing modes and 2 mm thick ceramic on tensile bond strength of resin cement to dentin, and 4) there was no effect of curing modes and 2 mm thick ceramic on failure modes after tensile bond strength test.

Materials and Methods

The study protocols were approved by the Ethics Committee in Human Research (Faculty of Dentistry/Faculty of Pharmacy, Mahidol University Institutional Review Board; MU-DT/PY-IRB 2025/DT022).

Evaluation of light-curing intensity

Ivoclar Bluephase N G4(Ivoclar Vivadent, Schaan, Liechtenstein) was used as a light curing unit. The mean and standard deviation of light intensity of both curing mode HIGH and TURBO were determined by measuring 10 times directly and under a lithium disilicate ceramic disc (Emax press, Ivoclar Vivadent, Schaan, Liechtenstein) in a truncated cone shaped with a diameter of 12 mm tapering down to 5 mm, height 2 mm with a cylindrical base area on the bottom side (Diameter = 5 mm, height = 0.5 mm) in shade LT A1 with 2mm thickness using LCM1000 light meter, SNLML-O 1103050 (APAZA, New Taipei City, Taiwan ROC).

Evaluation of the degree of conversion

To create a 100-micron cement thickness, a PVC sticker tape,100 microns in thickness with a circular hole of 5 mm in diameter, was applied to the glass slide (0.1 mm in thickness) to control the thickness. The Panavia V5 resin cement (Kuraray, Tokyo, Japan) was used in this study. Ten specimens were prepared for each of the three groups. For specimens in group 1, group 2, and group 3, a tooth primer was applied to the designated area and air-dried for 15 seconds, followed by the placement of mixed cement pastes on top of the primer. An additional glass slide (0.1 mm in thickness) was placed on top of the cement. Specimens in groups 2 and 3 were further light-cured through a ceramic disc of shade A1 LT (2 mm in thickness) on the top side (cement side) for 60 seconds at HIGH mode and TURBO mode, respectively. All specimens were wrapped in thin metal foil to prevent light exposure and were stored in 100% humidity at 37°C for 24 hours in a light-proof container.

After 24 hours, every specimen was subjected to the degree of conversion testing from 3 different areas on the top side (cement side) and bottom side (primer side, where cement contacted with the tooth primer) by Raman spectrometer (The LabRAM HR Evolution, HORIBA, Kyoto, Japan). The Raman spectra revealed characteristic peaks associated with the chemical structure of the resin matrix. The most notable changes upon curing occur at approximately 1638 cm^{-1} and 1608 cm^{-1}. The degree of conversion was calculated by monitoring the change in the ratio of absorbance peak heights between the aliphatic C double bond (C=C) at 1638 cm^{-1} and the aromatic C=C reference peak at 1608 cm^{-1}, comparing values before and after polymerization.

The DC for each specimen was determined using the following formula from Abed YA, Sabry HA, Alrobeigy NA. [12]

$$\boldsymbol{DC\%} = \left\{ 1 - \frac{\left(\frac{1638cm^{-1}}{1608cm^{-1}}\right) cured}{\left(\frac{1638cm^{-1}}{1608cm^{-1}}\right) uncured} \right\} \times 100\%$$

Evaluation of dentin bond strength

Tooth preparation

Freshly 30 extracted sound human third molars stored in solution saturated with thymol are used. The midcoronal dentin surfaces are created after the removal of the occlusal half of the crown using a low-speed diamond saw (Isomet, Buehler, Illinois, USA) to expose outer half dentin surfaces. Each specimen is individually secured to a cylindrical PVC mold (diameter: 25 mm, height: 15 mm), and self-curing polyester resin (Palavit G, Kulzer GmbH, Hanau, Germany) is poured to create a resin-embedded specimen block. The dentin surface is then wet polished with 320, 400, 600 grit SiC abrasive papers (CarbiMet, Buehler, Illinois, USA) to standardize the smear layer. A total of 30 polished specimens are prepared. The specimens are further divided into 3 groups of 10 specimens (one experimental group, chemical curing, and two experimental groups, 2 light-curing modes).

Ceramic discs fabrication

A total of 30 lithium disilicate ceramic discs were fabricated in a truncated cone shape. with a diameter of 12 mm tapering down to 5 mm, height 2 mm with a cylindrical base area on the bottom side (Diameter = 5 mm, height = 0.5 mm) in shade LT A1 (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein). The truncated cone shape provided a barrier to prevent interfering curing light from reaching the sides of the ceramic, while the base area was designed with the purpose of easily locking into the controlled bonding area. The bonding surfaces (5 mm in diameter) were etched with 5% hydrofluoric acid (IPS Ceramic Etching gel, Ivoclar Vivadent, Schaan, Liechtenstein) for 20 seconds, and a layer of ceramic primer (Kuraray, Tokyo, Japan) was applied and allowed to air dry for thirty seconds at room temperature. The surface treatments of the ceramic discs are according to the manufacturer's instructions.

Cementation

A PVC sticker tape (100 micron in thickness) with a circular hole of 5 mm diameter is applied onto the prepared flat dentin surface to control the area of bonding. The dentin surface was cleaned with pumice. Panavia V5 Tooth primer (Kuraray, Tokyo, Japan) was then applied onto the prepared area for 20 seconds and thoroughly

Ceramic discs, after being treated with a ceramic etchant and ceramic primer, were further cemented to the dentin surface of specimens in all experimental groups using Panavia V5 resin cement (Kuraray, Tokyo, Japan). The mixed resin cement was applied to the treated ceramic surface, and the ceramic disc was then pressed onto the dentin surface with a force of 15 N for 1 minute. Excess cement was removed with a disposable microbrush and left uncured for Experimental Group 1, while light curing was performed from the top surface using the HIGH mode for Experimental Group 2 and the TURBO mode for Experimental Group 3 for 60 seconds. The PVC sticker tape was then removed with a scalpel blade number 15. After the cementation procedures, all specimens were stored in 100% humidity at 37°C for 24 hours in a light-proof container.

Tensile bond strength test

All specimens were subjected to tensile strength test in a universal testing machine (LF Plus, Lloyd, West Sussex, England) at crosshead speed of 0.5 mm/min until bond failure was achieved.

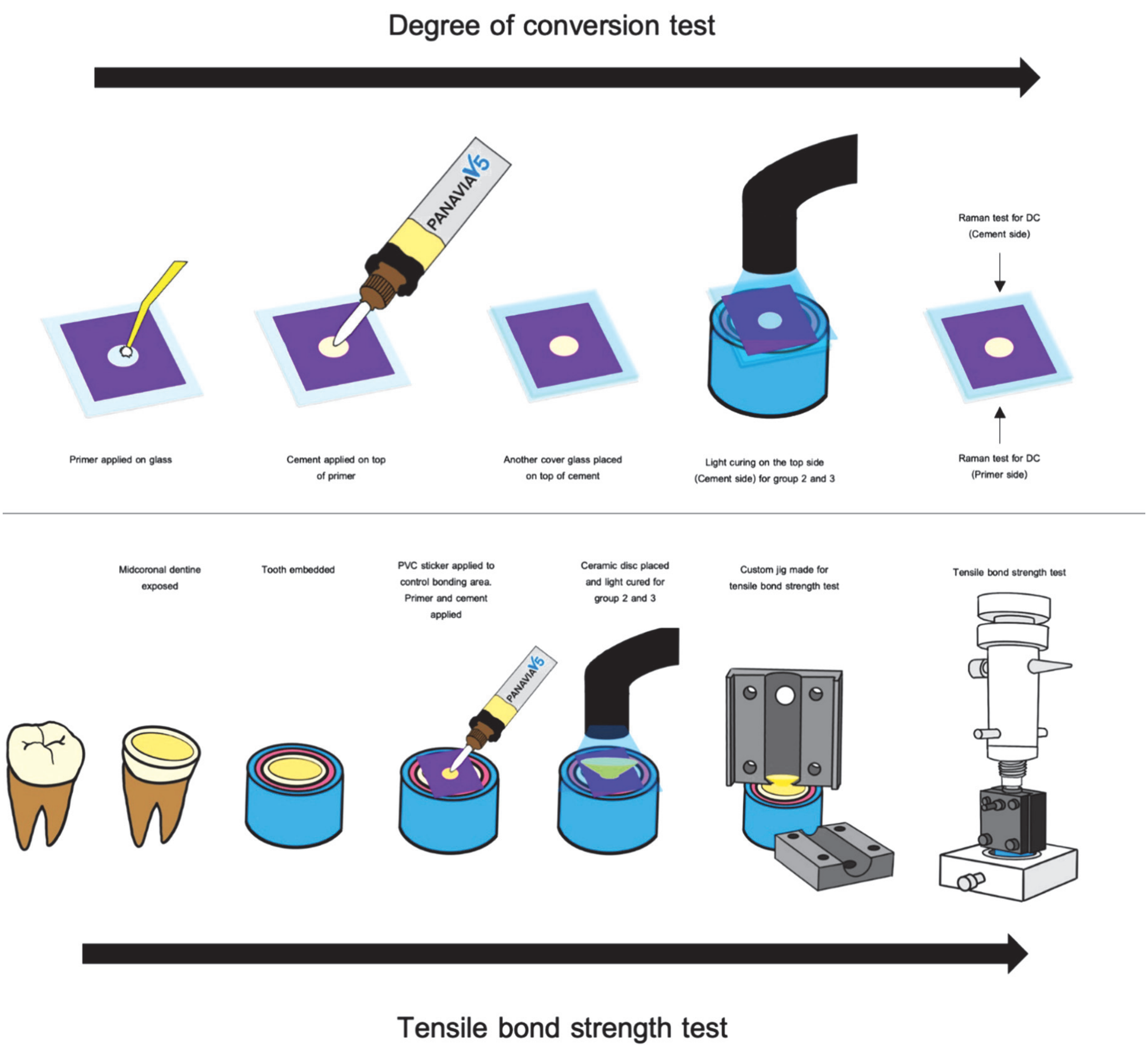

Figure 1 presents a schematic illustration of the experimental procedures for degree of conversion and tensile bond strength tests of dual-cure resin cement.

Observation of failure modes

The dentin surface of specimens after the tensile bond strength test from each group was air dried and observed under a 3D measuring laser microscope (Lext OLS5100, Olympus, Tokyo, Japan) at 5× magnification. The failures were classified into 1) cohesive failure within dentin and 2) adhesive failure. The fractured surface compositions were measured as a percentage using the ImageJ program (Wayne Rasband and contributors, National Institutes of Health, USA).

Statistical analysis

Light intensity, degree of conversion, bond strength, and failure modes were analyzed using parametric statistics with a significance level of $p<0.05$.

For the light intensity, the normality test with Kolmogorov-Smirnov showed $p\geq0.05$, and the homogeneity test with Levene's Test showed $p<0.01$. Further analysis was performed with 2-way ANOVA and Dunnet T3.

For the degree of conversion, the normality test with Kolmogorov-Smirnov showed $p\geq0.05$, and the homogeneity test with Levene's Test showed $p<0.1$. Further analysis was performed with 2-way ANOVA and Dunnet T3.

For bond strength, the normality test with Kolmogorov-Smirnov showed $p\geq0.05$ and the homogeneity test with Levene's Test showed $p=0.43$. Further analysis was performed with 1-way ANOVA and Scheffe multiple comparison.

For failure modes, the normality test with Kolmogorov-Smirnov showed $p<0.01$, and the homogeneity test with Levene's Test showed $p=0.09$. Further analysis was performed with 1-way ANOVA and Dunnet T3.

Subsequently, Pearson's correlation analysis was performed to assess the relationships between light intensity and the degree of conversion of the adhesive, light intensity, and the degree of conversion of the cement, and the degree of conversion of the cement and bond strength.

Results

Light intensity (mW/cm^2) with and without ceramic using different curing approaches is shown in Table 1. The light intensities of the direct HIGH and TURBO modes measured 1123 ± 4.83 mW/cm^2 and 1981 ± 11.00 mW/cm^2, respectively. When measured through a ceramic disc, 2-way ANOVA and Dunnet T3 showed the light intensities decreased substantially to 214 ± 18.97 mW/cm^2 for the HIGH mode and 469 ± 9.94 mW/cm^2 for the TURBO mode.

The degree of conversion (DC) was assessed on both cement and primer sides across the three experimental groups: group 1 (No LC), group 2 (HIGH), and group 3 (TURBO). Means and standard deviations are shown in Table 2. On the cement side, the DC values were 70.88 ± 0.55%, 73.56 ± 0.25%, and 75.94 ± 0.61% for groups 1, 2, and 3, respectively. On the primer side, the DC values were 98.91 ± 0.04%, 98.92 ± 0.03%, 98.93 ± 0.03% respectively. 2-way ANOVA revealed a significant effect of curing modes ($p<0.01$) and primer/cement ($p<0.01$) with interaction between these 2 factors ($p<0.01$). According to the multiple comparison with Dunnet T3, the primer side demonstrated significantly higher DC values when compared to the cement side ($p<0.01$). Meanwhile no statistically significant differences were observed among primer groups ($p = 0.95$). Significant differences of cement side DC were found (group 3>group2>group1) ($p<0.01$).

Table 1 Light intensity (mW/cm^2) with and without ceramic using either High or Turbo modes (mean ± standard deviation)

Measurement / LC mode	Direct Measurement	Measurement through ceramic
High	1123.00 ± 4.83[b]	214.00 ± 18.97[d]
Turbo	1981.00 ± 11.00[a]	469.00 ± 9.94[c]

Table 2 Light curing modes and degree of conversions of adhesive and cement

Light mode	DC adhesive	DC cement
No LC	98.91 ± 0.04%[A]	70.88 ± 0.55%[c]
HIGH	98.92 ± 0.03%[A]	73.56 ± 0.25%[b]
TURBO	98.93 ± 0.03%[A]	75.94 ± 0.61%[a]

The same letter indicates no statistically significant difference between groups within the same column ($p > 0.05$).

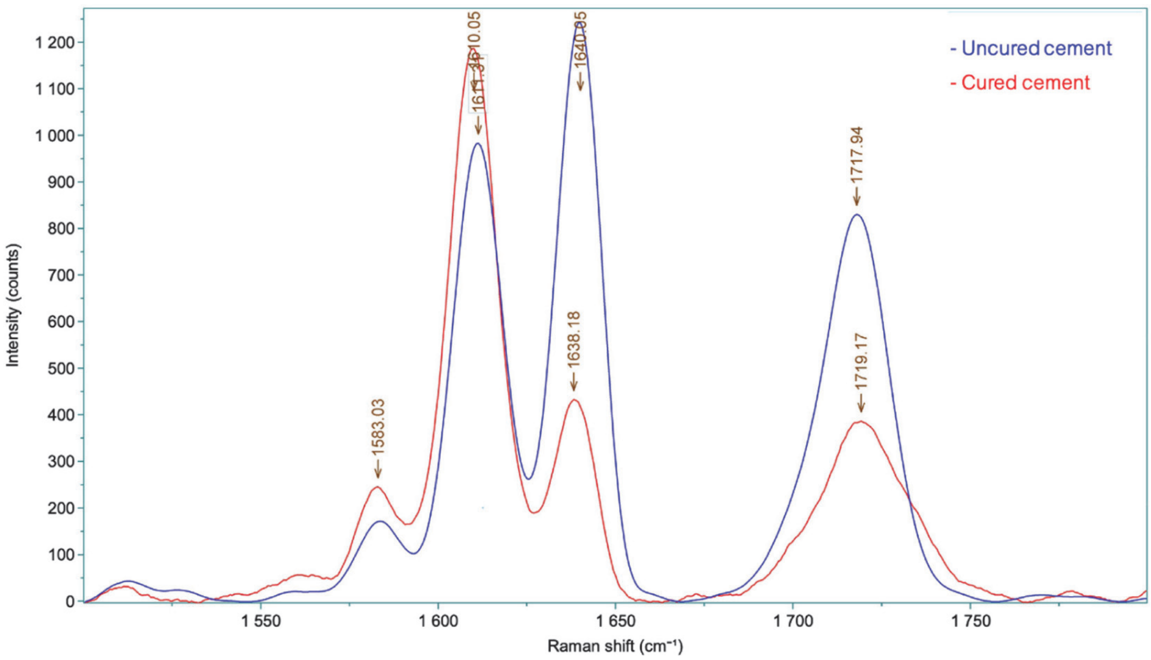

Figure 2 presents the Raman spectra of dual-cure resin cement in its uncured (blue) and cured (red) states. The spectra reveal characteristic peaks associated with the chemical structure of the resin matrix. The most notable changes upon curing occur at approximately 1638 cm^{-1} and 1608 cm^{-1}.

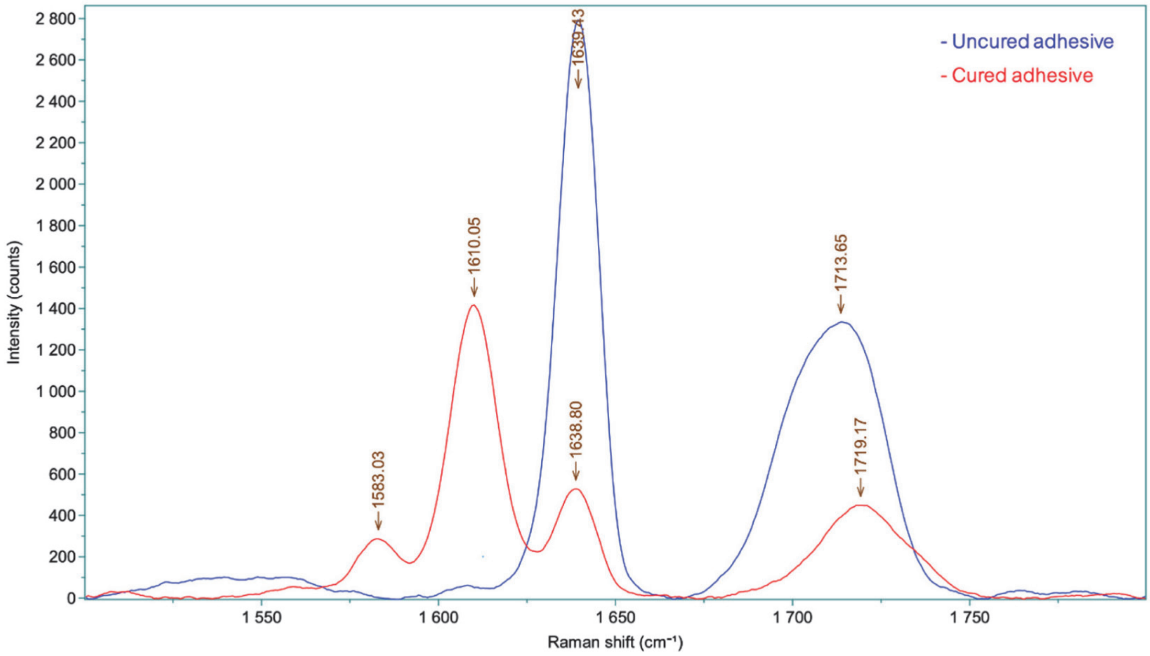

Figure 3 presents the Raman spectra of the primer in its uncured (blue) and cured (red) states. Key spectral features include peaks at approximately 1638 cm^{-1} (aliphatic C=C stretch) and 1608 cm^{-1} (aromatic C=C stretch).

Means and standard deviations of tensile bond strength of the resin cement to dentin are shown in Table 3. 1-way ANOVA and Scheffe multiple comparison revealed the bond strength of specimens in group 1 (No LC), which underwent only chemical curing, exhibited significantly lower tensile bond strength (TBS) mean values of 5.53 ± 0.93 MPa. In contrast, specimens in group 2 (HIGH), light-cured using the HIGH mode, demonstrated a higher TBS mean value of 11.27 ± 1.48 MPa. The highest TBS mean value of 14.52 ± 1.86 MPa was observed in specimens from group 3 (TURBO), which were light-cured using the TURBO mode. Statistically significant differences were observed among all groups (p<0.01).

Table 3 Light curing modes and bond strength

Light mode	Bond strength (mean ± standard deviation)
No LC	5.53 ± 0.93[c]
HIGH	11.27 ± 1.48[b]
TURBO	14.52 ± 1.86[a]

The percentage of failure modes are demonstrated in Figure 4. The analysis of failure modes by 1-way ANOVA and Dunnet T3 multiple comparison revealed that group 1 (No LC) exhibited predominantly adhesive failures 96.79±6.4%, with a small proportion of cohesive failures within dentin 3.21±6.4%. There were significant differences of group 1 when compared to group 2 and 3 at a significance level of $p<0.01$. group 2 (HIGH) demonstrated a lower percentage of adhesive failures 73.30±14.92% and a correspondingly higher percentage of cohesive failures 26.70±14.92%. group 3 (TURBO) showed a mixed failure pattern similarly to group 2, with adhesive failures accounting for 82.80±15.37% and cohesive failures comprising 17.20±15.37%. There were no significant differences between group 2 and 3 ($p=0.80$).

For the analysis or correlation, no statistically significant correlation was observed between light intensity and degree of conversion of the primer ($p=0.75$). In contrast, a significant positive correlation was found between light intensity and the degree of conversion of the cement ($p<0.01$), with a coefficient of determination (R^2) of 0.225. This relationship was further evaluated using linear regression analysis, resulting in the equation:

$y = 42.97x - 2929.47$ (y = conversion, x = intensity)

Moreover, a strong positive correlation was identified between the degree of conversion of the cement and its tensile bond strength ($p<0.01$, $R^2 = 0.84$). The regression model describing this relationship is following:

$y = 0.49x + 68.37$ (y = bond strength, x = degree of conversion).

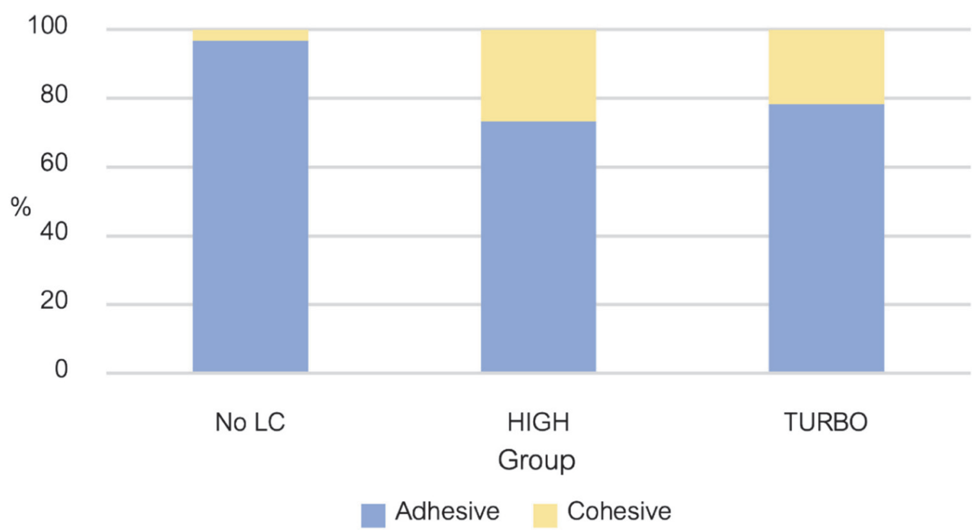

Figure 4 The ratio between adhesive and cohesive failure of experimental group No LC, HIGH and TURBO

Discussion

This study evaluated the effects of different light-curing modes (HIGH and TURBO) compared to chemical curing alone on the degree of conversion (DC), tensile bond strength (TBS), and failure modes of dual-cure resin cement when applied through a ceramic disc.

The uncured cement exhibited the lowest degree of conversion (DC) at 70.88±0.55%, while light curing led to significant increases in DC (HIGH mode: 73.56±0.25%, TURBO mode: 75.94±0.61%). On the primer side, no significant differences in DC were observed among the uncured, HIGH, and TURBO groups (98.91±0.04%, 98.92±0.03%, and 98.93±0.03%, respectively). As a result, the second null hypothesis concerning the primer was accepted, whereas the hypothesis for the cement side was rejected. The mean tensile bond strengths (TBS) for groups 1, 2, and 3 were 5.53 MPa, 11.27 MPa, and 14.52 MPa, respectively, with statistically significant differences observed. Therefore, the third null hypothesis was rejected.

The irradiance duration was standardized at 60 seconds based on the findings of Bansal R, Taneja S, and Kumari M [13], who reported that a 60-second light-curing protocol resulted in a significantly higher degree of conversion compared to a 40-second exposure when a dual-cure resin cement was polymerized beneath an IPS e.max Press ceramic restoration. The Ivoclar Bluephase N G4 (Ivoclar Vivadent, Schaan, Liechtenstein) was selected as the light-curing unit for this study, as it offers distinct curing modes, HIGH and TURBO, delivering markedly different irradiance outputs of 1123 ± 4.83 mW/cm² and 1981 ± 11.00 mW/cm², respectively. Panavia V5 resin cement (Kuraray, Tokyo, Japan) was selected for this study due to its touch-cure property, which facilitates efficient polymerization upon contact with the adhesive interface. Additionally, its selection was supported by a substantial volume of clinical and in vitro research demonstrating its favorable mechanical properties, reliable bond strength, and long-term stability across various restorative applications.

The results of DC test showed that the initial light intensities of the HIGH and TURBO modes were substantially reduced when measured through the ceramic disc. Other factors, such as thickness, opacity, and shade of restorative materials, can significantly reduce the light energy transmitted for the polymerization of light-cured resin systems [14,15]. Dental ceramics, in particular, can compromise the polymerization efficiency of underlying resin-based materials as thickness increases, as demonstrated by Pereira CB *et al.* [16]. Zhang X, Wang F. in 2011 [17] also found that the amount of light reaching the cement layer through a lithium disilicate ceramic (medium opacity, shade MO1) decreases to 45% under a 1 mm thickness, 16% under a 2 mm thickness, and about 8% under a 3 mm thickness. In this study, the transmitted irradiance in both modes was significantly lower (214 ± 18.97 mW/cm² for the HIGH mode and 469 ± 9.94 mW/cm² for TURBO mode) compared to the direct measurements (1123 ± 4.83 mW/cm² for the HIGH mode and 1981 ± 11.00 mW/cm² for TURBO mode), the fist null hypothesis was rejected. However, the irradiance remained within a range that allowed clinically acceptable polymerization with a DC between 60 and 75% for resin cements [18]. This finding was also supported by a study by Li *et al.* in 2021 [19] investigated the minimum irradiance and radiant exposure (RE) required to adequately polymerize a 0.1 mm thick dual-cure resin cement. They determined that an irradiance of 100 mW/cm² was sufficient to achieve adequate polymerization, as measured by microhardness and degree of conversion assessments. The irradiance exposure time of 60 seconds in this study could compensate for the relatively low irradiance power supported by a study by Ilie N. and Hickel R. 2007 [20].

The degree of conversion on the cement side exhibited an increasing trend across groups 1 (No LC), 2 (HIGH), and 3 (TURBO), with group 3 achieving the highest mean DC value. This correlation highlights the importance of light activation in optimizing the mechanical performance of dual-cure cements, aligning with previous reports [21-23] that demonstrated superior bond strength with combined chemical and light polymerization.

Interestingly, the primer side consistently demonstrated very high DC values (~98-99%) across all groups, with no significant differences among the groups. There were no correlations between light curing intensity and the degree of conversion of the primer. This finding can be associated with the touch-cure property of the system, facilitating more effective polymerization despite the ceramic barrier. A study by Yoshihara K. *et al*. in 2021[24] compared the effect of the accelerator-containing Panavia V5 Tooth Primer versus that of an experimental accelerator-free primer on DC and shear bond strength (SBS) to dentin. The highest degree of conversion was achieved by combining composite cement with chemical accelerator within the tooth primer. These findings underscore the clinical relevance of applying additional light curing when luting ceramics to dentin in order to ensure the optimal performance of dual-cure resin cements.

The conventional tensile bond strength test was conducted exclusively on specimens with relatively large bonded areas, measuring 5 mm in diameter. This method was chosen because the stresses are much more homogeneous across the interface compared to shear testing. Additionally, the conventional tensile test offers several advantages, including straightforward specimen preparation, comparability between different materials, and reduced sensitivity to variables when compared to micro-tensile testing [25, 26]. Furthermore, this conventional testing is well-suited for our ongoing study regarding the effect of cyclic loading on dentin bond strength. The larger specimen size may facilitate a more thorough investigation of the impact of fatigue loading on dentin bond strength. However, this means that the micro-scale interactions or interface characteristics observed in micro-testing may not be detected. Therefore, micro-tensile bond strength assessments could yield more valuable data.

TBS results showed clear and statistically significant differences among the groups. Specimens that were only chemically cured (group 1) exhibited significantly lower bond strengths compared to those that received additional light-curing (groups 2 and 3). The highest bond strengths were achieved in the TURBO mode group. This correlation coincides with the results from previous studies [23, 27].

The analysis of failure modes further supports the degree of conversion and bond strength findings. Group 1 predominantly exhibited adhesive failures, indicative of a weaker interface, whereas groups 2 and 3 showed an increased proportion of cohesive failures within the substrate, suggesting a stronger interfacial bond. There were significant differences between the failure modes among groups, resulting in rejection of the fourth hypothesis.

Even though there were no significant differences among DC of primer sides, the cement side exhibited significant differences in DC among all groups (No LC< High<Turbo). The failure modes in group High and Turbo showed higher cohesive failures within the substrate implying higher DC of cement which impacts the increase in TBS.

Conclusion

Within the limitations of this study, while the degree of conversion on the adhesive side did not correlate with curing, significant improvements were observed on the cement side due to light curing. The mechanical properties, as evidenced by the tensile bond strength (TBS) and failure mode distributions, were also notably enhanced.

In addition, only one commercial cement and one light source were used in this study; therefore, caution should be exercised when applying these findings to other products or equipment. Moreover, future research could focus on the long-term durability of these bonds under thermomechanical aging to simulate oral conditions more closely.

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