Effect of Different Light-Curing Modes on Bond Strength of Ceramic Laminate Veneers

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Purpose: To investigate whether high-level irradiance and short light exposure times with light-emitting diode (LED) curing units could provide bond strength comparable to halogen lights for ceramic laminate veneers (CLVs). Materials and Methods: A total of 160 extracted human maxillary central incisors were prepared to receive CLVs (lithium disilicate) in shades A1 and A3.5. CLVs were luted with light-curing (LC) and dual-curing (DC) resin cements using four protocols: 3 seconds in extra power mode, 8 seconds in high power mode, or 10 seconds in standard mode with an LED unit, or 40 seconds with a conventional halogen light from all aspects (n = 10). Following thermal cycles, shear bond strength test was performed with a universal testing machine. Data were analyzed using one-way analysis of variance and post hoc Tukey test. Failure modes were classified under a stereomicroscope, and data were analyzed using Pearson chi-square test (P = .050).

Results: According to the intragroup comparison of different irradiation protocols, the mean shear bond strength of the A1-LC-10 group was found to be significantly higher than that of the A1-LC-halogen group (P = .026). Shear bond strength values of the A1-LC-10 group and A3.5-LC-10 group were significantly higher than that of the A3.5-DC-10 group (P = .003). The A3.5-DC-3, A3.5-LC-3, and A1-DC-8 groups revealed the significantly most adhesive failures, and the A1-LC-8 group revealed the most mixed failures (P < .001).

Conclusion: Both light and dark ceramic shades with LC cement combination responded the best to the standard mode of 10-second exposure time with LED application. However, with conventional halogen light application, the highest bond strength values were obtained with DC cement and light ceramic shade combination. Int J Prosthodont 2021;34:221–228. doi: 10.11607/ijp.7029

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Ceramic laminate veneers (CLVs) are very popular restorations that combine minimally invasive and superior esthetic properties. The success of CLVs depends on a number of factors, including the ceramic system, properties of the resin cement, curing light, and curing regimen. The most common failure types of ceramic veneers are fracture and debonding. A strong bond between dentin/enamel resin cement and CLV resin cement is crucial for the clinical performance of the CLV. It is well known that the bond strength of ceramic laminate materials to enamel is superior compared to the bond strength to dentin. Therefore, it is highly recommended that if dentin exposure is unavoidable during tooth preparation, enough sound enamel must be left on the tooth surface.

Light-curing (LC) or dual-curing (DC) resin cements are commonly used for the cementation of all-ceramic restorations, as they adhere to dental tissues, provide satisfactory esthetics, have low solubility in the oral environment, and possess superior mechanical properties, which contribute to the reinforcement of ceramic restorations. Different activation systems of resin cements provide advantages, depending on the case. Due to their superior color stability and the working time controlled by the operator, LC cements are recommended for the cementation of CLVs. LC resin cements commonly contain aliphatic amines as photoinitiator, as they are less
susceptible to color change over time.\textsuperscript{5} However, when the thickness and opacity of the restoration are high, DC resin cements—which contain both a photoinitiator and a self-cure initiator—are advantageous. DC resin cements generally contain an aromatic tertiary amine as initiator of the self-curing reaction, which may lead to color change of the restorations over time.\textsuperscript{5–7} After a self-curing process, the polymerization is completed with more monomer conversion by the use of light curing. The resin cements used in the present study are claimed by the manufacturer to contain the amine-free photoinitiator Ivocerin. Factors that mainly affect the polymerization of resin cements are the chemical composition and filler particle size of the cement, shade, and thickness of the restoration,\textsuperscript{8} in addition to intensity and wavelength of the light and polymerization time.\textsuperscript{9} Inadequate polymerization is usually associated with poor physical properties and changes in strength, stiffness, water sorption, color stability,\textsuperscript{10–12} and biologic properties\textsuperscript{13} of the resin cements.

Recently marketed third-generation LED curing units aim at reducing costly chairside time. Modern LED curing units provide higher irradiances (1,000 to 1,500 mW/cm\textsuperscript{2}) than conventional quartz-tungsten halogen curing units (400 to 500 mW/cm\textsuperscript{2}).\textsuperscript{14} According to the manufacturer, the VALO curing light (Ultradent) with multiple light intensities can reach an irradiance of 1,000 mW/cm\textsuperscript{2} in standard power mode (SM), 1,400 mW/cm\textsuperscript{2} in high power mode (HM), and 3,200 mW/cm\textsuperscript{2} in extra power mode (XM). For each layer of the restoration, the manufacturer recommends 10 seconds irradiation in SM, 8 seconds irradiation in HM, and 3 seconds irradiation in XM.

The product of recommended curing time (s) and irradiance (mW/cm\textsuperscript{2}) is termed radiant exposure (also called “energy density” or “energy dose,” J/cm\textsuperscript{2}). Radiant exposure describes a simple reciprocal relationship: when irradiance decreases, the exposure time necessarily increases.\textsuperscript{15} There is a gap in the literature regarding how different radiant exposures affect the bonding ability of resin cements beneath CLVs with dark and light shades. In general, a 40-second curing with a 400 mW/cm\textsuperscript{2} irradiance is recommended to provide adequate polymerization when applied directly to the material.\textsuperscript{1,3} To the best of the authors’ knowledge, there have been no studies to date regarding the effects of different radiant exposures on the shear bond strength of CLVs.

The purpose of the present study was to compare the shear bond strength of CLVs in shades A1 and A3.5 cemented with DC and LC resin cements using different irradiances of an LED unit for 10, 8, and 3 seconds and a conventional halogen light with irradiation of 40 seconds. The null hypothesis was that there would not be any difference in shear bond strength of CLVs of A1 and A3.5 shades luted with DC and LC cements using different irradiations of an LED unit and a halogen light.

**MATERIALS AND METHODS**

**Sample Preparation**

This study was approved by the ethics committee of Erciyes University with a reference number of 2015/190. A total of 160 noncarious maxillary central incisors free of restorations and extracted for periodontal reasons within the last 6 months were selected for the study. Dental plaque, calculus, and periodontal fibers were removed from the teeth and stored in a 0.1% chloramine-T solution. Teeth were examined for cracks under a magnification of ×25 using a light microscope (Carl Zeiss Surgical) and subsequently embedded into autopolymerizing acrylic resin blocks 2 mm below the cementoenamel junction and stored in distilled water. Depth orientation grooves, which were set to be limited at the enamel (0.3 mm in depth at the cervical region and 0.7 mm at the midcoronal and incisal regions), were made to the facial surfaces of teeth using depth preparation burs (Sunshine Diamonds), and the grooves were marked with a pencil. Then, preparations were made without exceeding the depth orientation grooves with a diamond round-ended chamfer bur (Sunshine Diamonds) at the same diameters. The preparations ended 1 mm above the cementoenamel junction. No incisal edge reduction was made.

**Fabrication of the Veneers**

After all the teeth had been prepared, the preparation surfaces were coated with titanium oxide powder (Calidia Scan Spray, Whitepeaks Dental Solutions), and the specimens were scanned (DScan, EG Solutions). Laminate veneers were designed using a software (DentalCAD, exocad), as the thickness of the veneer should be 1 mm, which was beveled at the margins. Then, wax patterns were milled by a computer-aided manufacturing unit (DWX-50, Roland). Lithium disilicate laminate veneers (IPS e.max Press, Ivoclar Vivadent) were fabricated from the wax pattern using the lost wax technique by the same dental technician according to the instructions of the manufacturer. While 80 of the veneers were fabricated from low translucency shade A1 ingots, the other 80 were made from low translucency shade A3.5 ingots. CLVs were first sintered in a calibrated ceramic oven (Programat EP 3010, Ivoclar Vivadent) and then checked for fractures using ultraviolet light. The CLVs were measured with a caliper to check the uniformity of the thickness. Subsequently, the fit of each CLV was controlled with the corresponding tooth. Finally, the glaze material (IPS Ivocolor Glaze Paste, Ivoclar Vivadent) was applied to the CLVs in a thin layer and fired according to the recommendations of the manufacturer.
Bonding of the Veneers

The intaglio surfaces of the CLVs were etched with 5% hydrofluoric acid (IPS ceramic etching gel, Ivoclar Vivadent) for 20 seconds and then rinsed. The samples were cleaned in an ultrasonic bath filled with 95% isopropyl alcohol for 10 minutes and dried with air. They were then silanized (Monobond Plus, Ivoclar Vivadent), allowed to react for 60 seconds, and air dried.

Acid etching gel, which contains 37% phosphoric acid (Total Etch, Ivoclar Vivadent), was applied to the prepared surfaces of teeth for 15 seconds, then rinsed and air dried. An adhesive layer (Tetric N-Bond, Ivoclar Vivadent) was applied for 20 seconds and air thinned and light cured for 10 seconds in SM (VALO). DC (Variolink Esthetic DC, Ivoclar Vivadent) and LC (Variolink Esthetic LC, Ivoclar Vivadent) resin cement systems (both in the same shade, “light”) were selected for cementation. Compositions of the resin cements are shown in Table 1. DC resin cement was dispensed from an automixing syringe delivered by the manufacturer, and LC resin cement was in a single syringe dispenser. The resin cement was applied to the inner surface of the CLVs and pressed to the teeth under finger pressure by the same operator (F.Y.). The excess resin was removed using a microbrush. Then the CLVs were photopolymerized in direct contact from mesial, distal, incisal, and labial (from the middle third) aspects for the given durations (Fig 1) according to the test groups.

Initially, teeth were divided into four groups according to the ceramic shade (A1 or A3.5) and cement type (LC or DC): A1-LC, A1-DC, A3.5-LC, A3.5-DC. Then each of these groups was polymerized with four different light-curing regimes (LED for 3, 8, or 10 seconds, or halogen light for 40 seconds). Thus, a total of 16 groups were obtained (n = 10 each), shown in Fig 1.

Shear Bond Strength Test

All specimens were stored in light-proof containers in distilled water at 37°C for 1 week after cementation. Then the specimens were subjected to 5,000 thermal cycles alternating between 5°C and 55°C with a 15-second dwell time at each temperature (Julabo FT400). A shear bond strength test was performed with a universal
The load was applied to the incisal edge with an angle of 135 degrees to the long axis of the teeth by a specially designed apparatus in order to simulate the clinical conditions (Fig 2).

Failure modes were determined under a stereomicroscope (Leica S8AP0) at ×20 magnification (Fig 3) and classified as below:

- Cohesive failure in CLV
- Adhesive failure (debonding of CLV)
- Mixed failure (a combination of cohesive and adhesive failures in CLV)
- Cohesive failure in teeth

Statistical analysis was performed using SPSS version 25 (IBM). Normal distribution of the data was investigated using Kolmogorov-Smirnov test. After normal distribution was verified for all of the groups, the data were statistically analyzed using one-way ANOVA (Table 3). The mean shear bond strength of the A1-LC-10 group was found to be significantly higher than the A1-LC-halogen group (P = .026). The A1-DC (P = .290), A3.5-LC (P = .124), and A3.5-DC (P = .182) groups did not reveal any statistically significant difference according to light-curing protocols.

Irradiation times were also analyzed according to the groups. Shear bond strength values of the 3-second (P = .401), 8-second (P = .231), and halogen (P = .440) groups did not reveal any statistically significant difference. The means of the A1-LC-10 and A3.5-LC-10 groups were found to be significantly higher than the A3.5-DC-10 group (P = .003).

Analysis of Failure Modes
According to Pearson chi-square test, the A3.5-DC-3 (80.0%), A3.5-LC-3 (100.0%), and A1-DC-8 (100.0%) groups revealed a statistically significantly (P < .001) higher number of adhesive failures, and the laminate veneer separated from the tooth completely. The A1-LC-8 group revealed the most mixed failures (80.0%) (P < .001). Of the failures in ceramic, 6.9% were cohesive, 48.1% were adhesive, and 36.9% were mixed, while the percentage of cohesive failures in teeth was 8.1% (Table 4).

DISCUSSION
The bond strength of adhesive systems is commonly measured by shear or tensile bond strength tests because they require minimal equipment and specimen preparation. Since the shear bond strength test can be performed efficiently for brittle glass-ceramic materials
compared to tensile tests,\textsuperscript{17} the effects of the irradiance protocol, cement type, and ceramic shade on bonding performance of CLVs were investigated by using a shear bond strength test.

Cement type and properties could influence the failure of CLVs.\textsuperscript{2} Some studies have reported increased bond strength with LC resin materials compared to DC resin cements.\textsuperscript{18,19} Kameyama et al\textsuperscript{19} compared a DC resin cement to a direct composite resin as a luting material for ceramic inlays by using a microtensile bond strength test. The composite resin group resulted in higher bond strength with only one pretest failure, whereas the DC resin cement delivered lower bond strength values with a high rate of pretest failures.

Similarly, in the present study, the A1-LC and A3.5-LC groups revealed significantly higher shear bond strength values than the A3.5-DC group when 10-second SM irradiation was applied with the LED unit. However, halogen light application only achieved the highest bond strength values with the DC cement and light ceramic combination. It can be assumed that 40-second irradiation with a halogen light may have been inadequate curing for the LC cement used in this study. All these findings confirm that the null hypothesis of the current study should be partially rejected.

**Table 2** Irradiances, Exposure Durations, and Total Radiant Exposures of the Four Irradiation Protocols

<table>
<thead>
<tr>
<th>Irradiation protocols</th>
<th>Irradiance (mean ± SD), mW/cm(^2)</th>
<th>Exposure duration, s</th>
<th>Radiant exposure, J/cm(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED: XM</td>
<td>3,246 ± 76.3</td>
<td>3</td>
<td>9.7</td>
</tr>
<tr>
<td>LED: HM</td>
<td>1,654 ± 50.4</td>
<td>8</td>
<td>13.2</td>
</tr>
<tr>
<td>LED: SM</td>
<td>1,260 ± 42.5</td>
<td>10</td>
<td>12.6</td>
</tr>
<tr>
<td>Halogen light</td>
<td>305 ± 23.2</td>
<td>40</td>
<td>12.2</td>
</tr>
</tbody>
</table>

XM = extra power mode; HM = high power mode; SM = standard mode.
It has been observed that the degree of conversion of the monomers in DC resin cements decreases when they are activated under ceramic restorations, which may compromise the success of the ceramic restoration in the medium and long terms.²⁰,²¹ When higher irradiance reaches the surface of the resin-based material, more crosslinked polymer networks have been observed, and immediate trans-ceramic photoactivation was not capable of forming a highly cross-linked polymer.²² It was assumed that for DC cements, immediate exposure to light would lead to early vitrification, causing the restricted molecular mobility needed for the postpolymerization self-curing reaction and decreasing the degree of conversion of the resin cement.²³ For this reason, Souza et al.²⁴ recommended a delay period between cement mixing and light activation, which would provide a higher degree of conversion by increasing free-radical concentration. This study demonstrated that bond strength of the A3.5-LC-10 group was significantly higher than that of the A3.5-DC-10 second group. This result pointed out a deficiency of polymerization of the DC cement that could be attributed to fast polymerization, which affected the DC cements negatively. Moreover, Scotti et al.¹⁸ discovered that LC cement showed a higher degree of conversion and microhardness than DC cement when polymerized under the ceramic disc.

### Table 3  Mean ± SD Shear Bond Strength in the Irradiation Groups

<table>
<thead>
<tr>
<th>Groups (n = 10)</th>
<th>XM, 3 s</th>
<th>HM, 8 s</th>
<th>SM, 10 s</th>
<th>Halogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1-LC</td>
<td>305.60 ± 103.75&lt;sup&gt;a,b,A&lt;/sup&gt;</td>
<td>272.12 ± 57.25&lt;sup&gt;a,b,A&lt;/sup&gt;</td>
<td>370.59 ± 128.99&lt;sup&gt;A&lt;/sup&gt;</td>
<td>244.65 ± 57.79&lt;sup&gt;b,A&lt;/sup&gt;</td>
</tr>
<tr>
<td>A1-DC</td>
<td>223.82 ± 76.76&lt;sup&gt;A&lt;/sup&gt;</td>
<td>273.79 ± 29.42&lt;sup&gt;A&lt;/sup&gt;</td>
<td>288.63 ± 137.34&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>320.74 ± 158.38&lt;sup&gt;a,A&lt;/sup&gt;</td>
</tr>
<tr>
<td>A3.5-LC</td>
<td>283.22 ± 114.61&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>222.16 ± 113.36&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>308.10 ± 53.32&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>244.06 ± 94.2&lt;sup&gt;a,A&lt;/sup&gt;</td>
</tr>
<tr>
<td>A3.5-DC</td>
<td>264.32 ± 133.41&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>331.04 ± 129.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>206.87 ± 40.98&lt;sup&gt;a,B&lt;/sup&gt;</td>
<td>279.52 ± 141.33&lt;sup&gt;a,A&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

XM = extra power mode; HM = high power mode; SM = standard power mode.
The same superscript lowercase letter denotes a statistical difference between rows, and the same superscript uppercase letter denotes a statistical difference between columns (P < .05).

### Table 4  Analysis of Failure Modes

<table>
<thead>
<tr>
<th>Groups</th>
<th>A, %</th>
<th>B, %</th>
<th>C, %</th>
<th>D, %</th>
<th>Pearson chi-square</th>
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<tbody>
<tr>
<td>A1-DC-halogen</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>A1-LC-halogen</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>A3.5-DC-halogen</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>70&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>A3.5-LC-halogen</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>A1-DC-3</td>
<td>20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>A1-LC-3</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>A3.5-DC-3</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>A3.5-LC-3</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>P &lt; .001</td>
</tr>
<tr>
<td>A1-DC-8</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>P &lt; .001</td>
</tr>
<tr>
<td>A1-LC-8</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>P &lt; .001</td>
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<tr>
<td>A3.5-DC-8</td>
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<td>NS</td>
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<tr>
<td>A3.5-LC-8</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>60&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
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<tr>
<td>A1-LC-10</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>A3.5-DC-10</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>A3.5-LC-10</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>% of total</td>
<td>6.9</td>
<td>48.1</td>
<td>36.9</td>
<td>8.1</td>
<td>NS</td>
</tr>
</tbody>
</table>

A = cohesive failure in ceramic laminate veneer (CLV); B = adhesive failure (complete debonding of CLV); C = mixed failure; D = cohesive failure in teeth; NS = not significant. Different superscript letters indicate a significant difference within the row (P < .05).
It is recommended to evaluate the quality of the bond based not only on bond strength data, but also on the analysis of failure modes. Most of the failure modes of the study were adhesive (48.1%), which included complete debonding of CLVs. The A1-DC-8 group exhibited 100% adhesive failure, which might be caused by the rapid vitrification of the DC cement with high radiant energy. On the other hand, the A1-DC-3 group exhibited 40% adhesive failure. It was assumed that due to the applied load from the incisal edge, stress was concentrated at the interface of the tooth and restoration. However, when adhesive strength is strong enough, cohesive failure occurs at the ceramic or tooth.

Adhesive failure ratios in the A3.5-DC-3 (80%) and A3.5-LC-3 (100%) groups were also significantly higher. Radiant exposure of these groups, which were irradiated in XM for 3 seconds, was the lowest (9.7 J/cm²) among the groups. This result can be attributed to the inadequate polymerization due to the shade and radiant exposure, apart from resin cement type. However, the failure loads are not in accord with the failure modes. Amato et al demonstrated that a 6-second exposure with 760 mW/cm² irradiance provided a satisfactory degree of curing. A 3-second exposure with increased irradiance (1,520 mW/cm²) caused a slight decrease in the degree of conversion, while surface microhardness was affected positively. Radiant exposure level was held constant for all groups in that study (4.56 J/cm²). In the present study, the lowest applied radiant exposure was the 3-second exposure in XM, and the highest was the 8-second exposure in HM of the LED unit. However, shear bond strength differed statistically only between the A1-LC-10 and A1-LC-halogen groups, which could be due to the higher radiant exposure in SM of the LED unit for 10 seconds than with the halogen light and LC cement used. The failure mode ratios of the present study did not exactly follow the pattern of shear bond strength test results. The morphologic and possible histologic differences of the natural teeth and irregularities created during the processing of ceramic material might have affected the results obtained with bond strength tests. Another limitation of the study was dependent on the teeth preparations for the veneers. Preparations were standardized and limited on the enamel surface. However, subjectiveness of the operator may have led to minimal differences.

Faria-E-Silva and Pfeifer investigated the effectiveness of high-power LEDs to polymerize resin cements through ceramics. Light polymerization with VALO in SM for 20 seconds resulted in a higher degree of conversion than in XM for 3 seconds when cured beneath 1-mm and 2-mm ceramic thicknesses. Generally, curing in XM for 3 seconds showed a tendency to lower the degree of conversion, which was not statistically significant for control (without ceramic) and 0.5-mm ceramic thickness. However, for 1- and 2-mm ceramic thicknesses, irradiation in XM mode for 3 seconds showed a significantly lower degree of conversion than for 20-second irradiation with VALO in SM. Lührs et al also recommended extending the LC time, especially when light attenuation due to the thickness/shade/opacity of the restoration is expected. The observation that the use of very high-energy densities does not lead to significant increases in the degree of conversion and may significantly increase polymerization contraction stress seems to corroborate the present results. Similarly, Kanamori et al stated that higher irradiance did not always provide higher bond strength for DC resin cements, and the degree of conversion did not always correlate with the dentin bond strength.

It was reported that extracted incisor teeth restored with CLVs exhibited their original strength. Dimensions of the teeth used in a study is a critical factor that can affect the results due to the difference in the bonding surface area. Therefore, the equality of the groups was confirmed by statistical analysis. Extracted human teeth can vary in fragility and enamel properties depending on age. Phosphoric acid etching was applied for 15 seconds in the present study according to the manufacturer’s recommendation for cut enamel surfaces. However, the results may change with prolonged application of acid etching.

Öztürk et al investigated shear bond strength of CLVs to enamel, dentin, and the enamel-dentin complex and found that CLVs bonded to dentin exhibited the lowest bond strength value, followed by, respectively, the enamel-dentin complex and enamel. In the study, an enamel reduction of 0.3 mm at the cervical and 0.7 mm at the midcervical and incisal regions were recommended to remove the hypermineralized enamel top surface, which can be resistant to acid etching. The preparation depth was set to be limited to the enamel to provide the maximum bond strength and also to constitute homogenous bonding surfaces.

It has been confirmed that different resin materials react differently to light exposure time and intensity. Moreover, ceramic thickness, which was kept constant in this study, is also an effective factor influencing the bond durability of the veneers. Further studies including different ceramic thicknesses and different resin cements are needed to determine whether short and prolonged light exposure times with high irradiance optimize the properties and bonding performance of the contemporary resin cements used in dental clinics.

**CONCLUSIONS**

This study demonstrated that ceramic shade, exposure time, and intensity of light source could affect the bond strength of CLVs cemented with DC or LC resin cements.
Both light and dark ceramic shades with LC cement combination responded the best to 10-second exposure time in SM with LED application. However, with conventional halogen light application, the highest bond strength values were obtained with DC cement and light ceramic shade combination. This study suggests that LC resin cements might be advantageous over DC resin cements when luting CLVs. Considering the higher adhesive failure ratios of the 3-second and 8-second groups, longer light exposure times might be advantageous for cementation of CLVs.

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