

# Effect of Temperature on the Degree of Conversion and Working Time of Dual-Cured Resin Cements Exposed to Different Curing Conditions

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## Clinical Relevance

A high degree of conversion can be achieved when dual-cured resin cements are used with increased temperature even when the curing light is compromised by the presence of ceramic restorations. However, caution is recommended before the clinician decides to warm up the resin cement, as this procedure may compromise the working time, depending on the temperature and product.

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## SUMMARY

**Objectives:** This study evaluated the degree of conversion (DC) and working time (WT) of two commercial, dual-cured resin cements polymerized at varying temperatures and under different curing-light accessible conditions, using Fourier transformed infrared analysis (FTIR).

**Materials and Methods:** Calibra (Cal; Dentsply Caulk) and Variolink II (Ivoclar Vivadent) were tested at 25°C or preheated to 37°C or 50°C and applied to a similar-temperature surface of a horizontal attenuated-total-reflection unit (ATR) attached to an infrared spectrometer. The products were polymerized using one of four conditions: direct light expo-

sure only (600 mW/cm<sup>2</sup>) through a glass slide or through a 1.5- or 3.0-mm-thick ceramic disc (A2 shade, IPS e.max, Ivoclar Vivadent) or allowed to self-cure in the absence of light curing. FTIR spectra were recorded for 20 min (1 spectrum/s, 16 scans/spectrum, resolution 4 cm<sup>-1</sup>) immediately after application to the ATR. DC was calculated using standard techniques of observing changes in aliphatic-to-aromatic peak ratios precuring and 20-min postcuring as well as during each 1-second interval. Time-based monomer conversion analysis was used to determine WT at each temperature. DC and WT data (n=6) were analyzed by two-way analysis of variance and Tukey *post hoc* test (*p*=0.05).

**Results:** Higher temperatures increased DC regardless of curing mode and product. For Calibra, only the 3-mm-thick ceramic group showed lower DC than the other groups at 25°C (*p*=0.01830), while no significant difference was observed among groups at 37°C and 50°C. For Variolink, the 3-mm-thick ceramic group showed lower DC than the 1-mm-thick group only at 25°C, while the self-cure group showed lower DC than the others at all temperatures (*p*=0.00001). WT decreased with increasing temperature: at 37°C near 70% reduction and at 50°C near 90% for both products, with WT reduction reaching clinically inappropriate times in some cases (*p*=0.00001).

**Conclusion:** Elevated temperature during polymerization of dual-cured cements increased DC. WT was reduced with elevated temperature, but the extent of reduction might not be clinically acceptable.

## INTRODUCTION

Dual-cured resin cements were developed to achieve optimal polymerization, even when the curing light is attenuated or blocked by the presence of an indirect restoration. For this purpose, polymerization of these products can be initiated by three activation modes: light-cure, self-cure or the association of both (dual cure).<sup>1,2</sup> Previous work indicates that the self-cure mode is less effective than the dual-cure mode since these cements produce lower degrees of conversion (DC) when access to the curing light is attenuated or blocked by the presence of an indirect restoration rather than when they are directly exposed.<sup>3-5</sup> In these detrimental clinical conditions, dual-cured resin cements may present lower hardness, higher solubility, lower flexural and

compressive strengths, and lower bond strength values to dentin when compared to resin cements that are directly light cured.<sup>6-13</sup> Compromised light delivery to dual-cure cements is a common clinical reality, as only 10% to 15% of light remains after passing through a 2-mm-thick indirect restoration, with shade varying from A2 to A4.<sup>3,9,14</sup>

One possible explanation for the lower effectiveness of self-curing components in dual-cured resin cements is related to the slow rate of polymerization activation and subsequent propagation of radicals in comparison to a directly photoactivated product.<sup>15</sup> After reaching a maximal rate of cure, this slow self-polymerization reaction passes through a phase called autodeceleration caused by a decrease in monomer and free radical mobility, resulting from the increase in network formation and resultant elevation in viscosity.<sup>16</sup> The viscosity of self-curing reactions impacts polymerization kinetics to a greater extent than those that are photocured only.<sup>17</sup> Another factor responsible for the poorer performance of self-curing components is related to the low amount of benzoyl peroxide able to be incorporated into these materials as well as the need to include inhibitors to prolong product shelf-life and provide a clinically realistic working time (WT), ranging from 2 to 5 minutes. For these reasons, the composition of dual-curing products still needs to provide the clinician with a reasonable WT, typically from 3 to 5 minutes.

The polymerization kinetics and mechanical properties of polymers are affected by temperature.<sup>18-20</sup> Increased resin temperature prior to and during polymerization leads to higher DC values for light-cured resin composites.<sup>21</sup> An increase in temperature during polymerization promotes free radical and monomer mobility, leading to higher polymerization rates and elevated DC.<sup>21,22</sup> As a consequence, preheated resin composites may reach similar DC as those exposed to room temperature, establishing a clinical advantage of this procedure by using shorter exposure durations.<sup>23,24</sup>

Following this line of thought, increasing the temperature of dual-cured resin cements during the mixing procedure may be a valuable option to promote optimal polymerization when resin cements rely mostly on the self-curing mode. However, the optimum precementation temperature for a specific material may result in clinically unacceptable WT. Only a few studies have evaluated the effects of increased temperature on marginal adaptation and bond strength of indirect restorations to tooth with dual-cure resin cements.<sup>25,26</sup> Higher bond strength

Table 1: Brand, Composition, and Batch Number of the Dual-Cured Resin Cementing Systems	
Product (Manufacturer)	Composition (Batch Number)
Calibra regular viscosity shade medium (Dentsply Caulk)	Base paste: barium boron fluoroalumino silicate glass, Bis-GMA resin, polymerizable dimethacrylate resin, hydrophobic amorphous fumed silica, titanium dioxide; other colorants are inorganic iron oxides.
	Catalyst paste: barium boron, fluoroalumino silicate glass, Bis-GMA resin, polymerizable dimethacrylate resin, hydrophobic amorphous fumed silica, titanium dioxide, benzoyl peroxide (base: 081105; catalyst: 0812011)
Variolink II low viscosity (Ivoclar Vivadent/Schaan, Liechtenstein)	Paste of dimethacrylates, inorganic fillers, ytterbiumtrifluoride, initiators, stabilizers and pigments, Bis-GMA, TEGDMA, urethane dimethacrylate, benzoyl peroxide (base: L46354; catalyst: L36656)
Abbreviations: TEGDMA, triethylene glycol dimethacrylate; bis-GMA, bisphenol A diglycidyl ether methacrylate.	

results obtained by the association between elevated DC and improved marginal adaptation have been attributed to the lower viscosity observed in resin cements at higher temperatures.<sup>25,26</sup> However, no information regarding monomer conversion and WT of such cements when polymerized at higher temperatures is available.

The purposes of this study were to evaluate the effects of increased temperature prior to and during polymerization of commercial dual-curing resin cements on their DC, time-based conversion profiles, and WT. In addition, the influence of different polymerization activation modes correlated with varied light attenuation scenarios was tested. The first research hypothesis anticipated that dual-cured resin cements polymerized at either 37°C or 50°C will demonstrate higher DC than the same products polymerized at room temperature. This result is expected even when the curing light is attenuated by the presence of indirect ceramic restorations with varying thickness or when no curing light is available; the material is allowed to polymerize totally in the self-cure mode. The second hypothesis expected to find a significant decrease in WT when the temperature during polymerization is increased to either 37°C or 50°C over that seen at room temperature (25°C).

MATERIALS AND METHODS

Specimen Preparation

The specific dual-cure resin cement products selected for testing (Table 1) were chosen for their differing ability to polymerize according to activation mode, as previously reported:<sup>27,28</sup> a product demonstrating better self-cure and light cure (Calibra

Regular, Dentsply Caulk, Milford, DE, USA) and a product producing poor self-cure (Variolink II low viscosity, Ivoclar Vivadent, Schaan, Liechtenstein). Ceramic discs of varying thickness were selected to model indirect restorative materials that offer different levels of light transmission to an underlying dual-cured resin cement: 2-cm diameter by either 1.5- or 3.0-mm thickness (IPS e.max, A2 shade, Ivoclar Vivadent).

In order to provide elevated resin temperatures during polymerization (37°C or 50°C), the base and catalyst pastes were equally dispensed on a glass plate that had been placed on a heated stirrer surface (103, Cientec, Piracicaba, São Paulo, Brazil) set at 37 ± 1°C or 50 ± 1°C. Resin and glass plate temperatures were constantly measured with a K-type thermocouple (SmartMether, Novus, Porto Alegre, RS, Brazil) to ensure that the paste components reached the desired temperature for each experimental group prior to their mixture. Once the proper temperature value had been reached, the cement components were hand mixed using a metal spatula and were then applied to the horizontal diamond element of an attenuated total reflectance (ATR) unit attachment (Golden Gate, Specac, Woodstock, GA, USA) in the optical bench of a Fourier transform infrared spectrometer (Tensor Series, Bruker Optik GmbH, Ettlingen, Germany). Prior to resin placement, adhesive tape (3M, St. Paul, MN, USA) was placed around the diamond surface to act as a spacer, ensuring standard thickness for all specimens (100–120 μm). For the preheated groups, the diamond surface temperature was elevated to 37°C or 50°C using a custom-made heating device, with the surface temperature constantly monitored

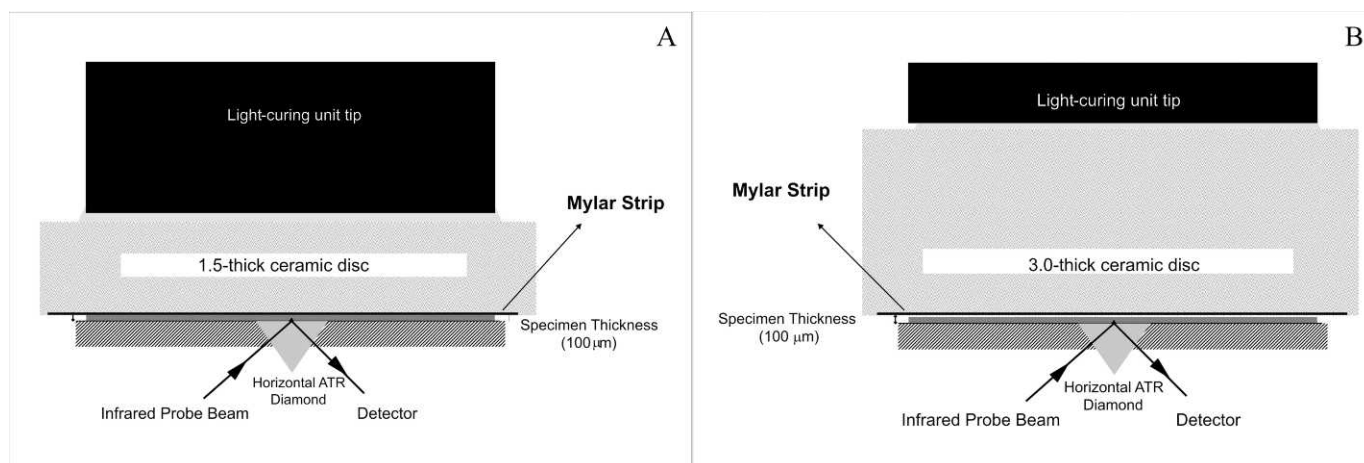


Figure 1. Illustrative diagram demonstrating the interaction between the infrared beam and the specimen, as well as the position of the 1.5- (A) or 3.0-mm (B) thick ceramic disc and the light-curing unit tip.

using the K-type thermocouple (SmartMether) during resin cement polymerization. For groups of resin cements polymerized at room temperature, all procedures described above were performed at 25°C.

The deposited resin cement was covered with a Mylar strip and polymerized using one of four different curing modes: direct light exposure, exposure to attenuated light by the presence of either 1.5- or 3.0-mm thick overlying ceramic discs, and total absence of curing light (self-curing mode). Specimens were exposed directly to light activation (manufacturer-recommended conditions of 20 seconds for Calibra and 40 seconds for Variolink II) from a light source emitting 600 mW/cm<sup>2</sup> (Optilux 501, Demetron Kerr, Danbury, CT, USA). The specimens were exposed without any overlying restorative material (direct light exposure [DLE], control group). The emitting end of the light guide was placed directly against a 2-mm-thick glass slide, positioned directly over top of the Mylar-covered resin specimen. When exposing cements to light using different thickness of overlying ceramic discs, the discs were placed directly between the Mylar sheet and the emitting end of the light guide (Figure 1). In addition, specimens were also allowed to polymerize in the total absence of the curing light by merely placing the 2-mm-thick glass slide over the Mylar and not supplying any photoactivating light (self-cure).

### Degree of Conversion

Infrared spectra were collected between 1680 and 1500 cm<sup>-1</sup> at a rate of one spectrum per second (16 scans/spectrum) at 4 cm<sup>-1</sup> resolution. Data were counted from the moment the infrared scan demon-

strated that the resin was stabilized on the ATR surface and any overlying objects had been placed. Spectra were recorded continuously during each 1-second interval for 20 minutes. Six replications were made for each test condition (n=6) based on previous studies using the same methodology.<sup>3,27-29</sup> Monomer conversion was calculated using standard methods that evaluated changes in the ratios of aliphatic-to-aromatic C=C absorption peaks (1636 cm<sup>-1</sup>/1608 cm<sup>-1</sup>) in the uncured and cured states obtained from the infrared spectra.<sup>30,31</sup> Prior to determining conversion, calibration graphs were made relating the absorbance ratios of known molar concentrations of aliphatic and aromatic C=C to their respective absorbance height ratios. Conversion values among all curing modes were compared statistically within each product only at 20 minutes from the time the resin cement was stabilized on the ATR surface. All polymerized specimens were carefully removed from the ATR plate and measured for thickness to the nearest 0.01 mm using a digital micrometer (Series 406, Mitutoyo America Corp, Aurora, IL, USA) to ensure similar thickness among all specimens.

### Working Time

For purposes of the study, WT was defined as the moment when infrared spectra first indicated evidence that conversion values rose above that of the zero-value baseline. Thus, individual analysis of polymerization kinetic graphs from each specimen was performed to determine the time (in seconds) elapsed between the first Fourier transformed infrared analysis spectrum and the moment when polymerization started (Figure 2).



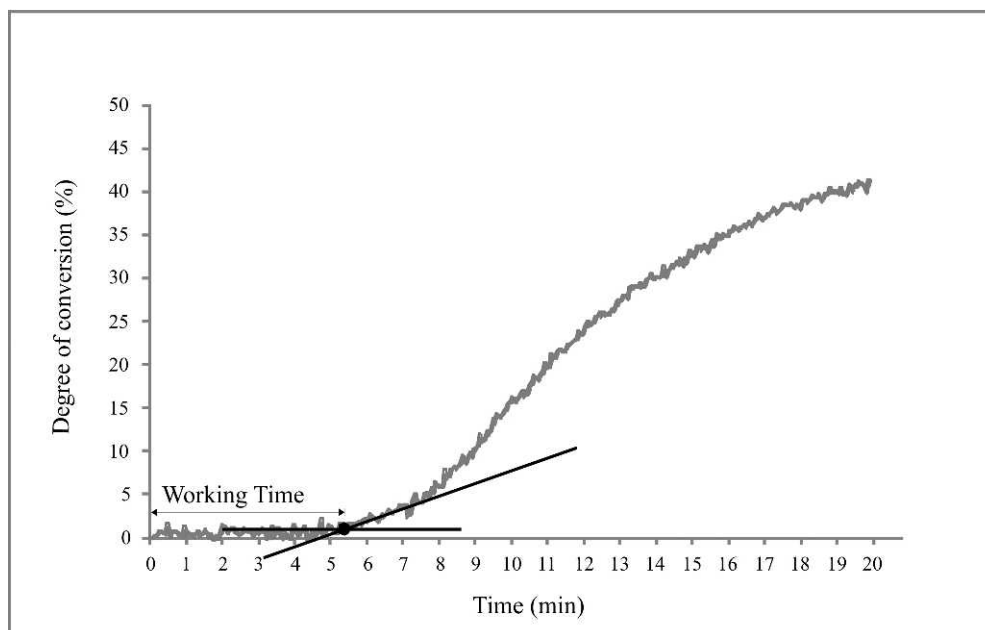


Figure 2. Illustrative polymerization kinetics of Variolink II polymerized by the self-curing mode exhibiting the time elapsed before the beginning of polymerization.

### Statistical Analyses

Degree of conversion data was evaluated within each dual-cure resin product using a two-way analysis of variance (ANOVA; factors: temperature [three levels] and curing condition [four levels]) followed by Tukey *post hoc* test. Direct comparison of conversion values between products was not made, because the result would not have had any meaning; only when resins have the same chemical formulation can such comparisons be made. The results of WT were pooled for the factor of curing mode and were subjected to two-way ANOVA (factors: temperature [three levels] and product [two levels]) followed by Tukey *post hoc* test. All testing was performed at a preset alpha of 0.05 using personal statistical software (SAS 8.0 for Windows, SAS Institute Inc, Cary, NC, USA). Post hoc power analysis was performed for the statistical analysis of DC and WT data using G\*3 Power statistical software.<sup>32</sup>

## RESULTS

### Degree of Conversion

For the number of specimens used ( $n=6$ ), the study was adequately powered for both factors, temperature and curing mode (over 95%;  $\alpha=0.05$ ). For both products, the two-way ANOVA indicated that the interaction between curing mode and temperature was a significant factor in affecting DC for both Calibra ( $p=0.01830$ ) and Variolink II ( $p=0.00001$ ).

Table 2 presents the DC of dual-cure cements exposed using the four curing conditions at three temperatures. Temperature increase resulted in significantly higher DC regardless of curing mode and product. The effect of different curing conditions on DC varied according to the temperature for both cements. For Calibra at 25°C, a lower DC was observed only when the thick ceramic disc was used in comparison to the DC of groups with other modes of attenuation, while no significant difference in DC was noted among curing conditions at either 37°C or 50°C. At 25°C, DC of the DLE and thin ceramic groups of Variolink II were the highest and not significantly different. However, use of the thick ceramic disc resulted in lower DC, and the lowest value was seen in the self-cure group. At 37°C, the DLE group showed the highest DC, while curing this material under either thickness of ceramic demonstrated less conversion. Again, the lowest conversion was seen using the self-cure condition. At 50°C, no significant difference in DC was noted among groups utilizing any form of light curing, while DC of the self-cure group was significantly lower.

Figures 3 and 4 show the effects of temperature on the time-based conversion profiles of Calibra and Variolink II, respectively, including comparison to the 20-minute DC value from DLE group at 25°C (dashed line) as control. At 25°C (Figure 3A), time-based conversion changes measured through the thin and thick ceramic discs and the self-cure group

Table 2: Degree-of-conversion means (Standard Deviation) of Calibra and Variolink II Exposed to Three Temperatures and Four Curing Modes<sup>a</sup>

Resin Cement	Temperature	Direct Light Exposure	Thin Ceramic Disc	Thick Ceramic Disc	Self-Cure
Calibra	25°C	55.9 (1.4) Aa	56.0 (1.9) Aa	52.9 (1.6) Ab	56.0 (1.2) Aa
	37°C	63.2 (0.9) Ba	62.4 (0.7) Ba	62.9 (1.1) Ba	61.7 (1.0) Ba
	50°C	67.3 (2.3) Ca	67.7 (1.3) Ca	67.2 (2.6) Ca	66.0 (1.6) Ca
Variolink II	25°C	62.3 (0.7) Aa	59.9 (2.4) Aa	54.5 (3.2) Ab	41.7 (1.0) Ac
	37°C	67.3 (1.4) Ba	64.1 (1.8) Bb	63.6 (1.3) Bb	56.8 (1.3) Bc
	50°C	72.6 (1.1) Ca	72.4 (1.3) Ca	70.3 (1.3) Ca	65.6 (1.0) Cb

<sup>a</sup> Significant differences are indicated by different letters (uppercase letters within column; lowercase letter within row) according to Tukey post hoc test at a preset alpha of 5%. No comparisons were made between products.

of Calibra exhibited DC values as high as those observed in the DLE groups at 20 minutes. The rate of conversion observed when directly exposing the cement (DLE) was very high at first, until the light-curing unit shut off, and then a slow, continual increase was noted. When exposing the cement through the thin ceramic disc, the curing rate was less than the DLE mode but more rapid than when

the thicker ceramic disc was interposed. The slowest initial curing rate was noted for the self-cure-only mode. Interestingly, the basic profile of time-based conversion for light curing through the ceramic discs appeared very much like that of the self-cure-only group, indicating that the overall polymerization reaction when curing through the ceramic discs was related to the self-cure reaction. At 37°C (Figure 3B)

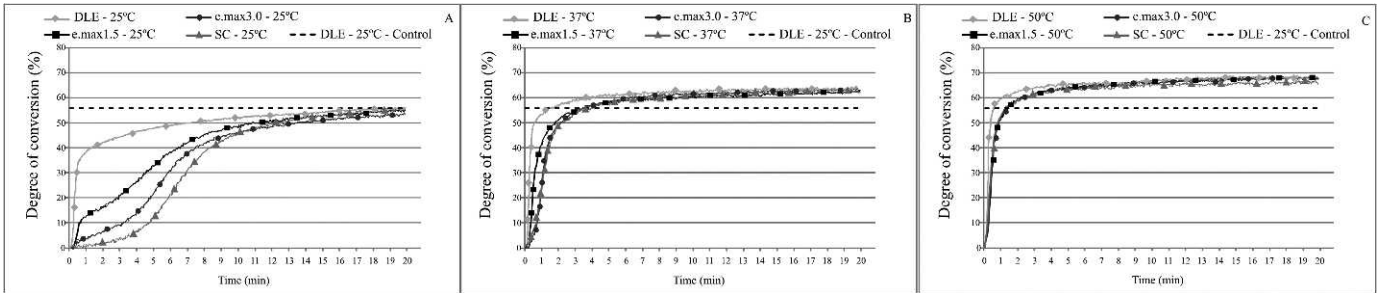


Figure 3. Polymerization kinetics of Calibra at a 25°C (A), 37°C (B), and 50°C (C) exposed to four curing conditions. The dashed line represents the degree of conversion after light activation through a glass slide at 25°C. Thin ceramic disc: e.max1.5; thick ceramic disc: e.max3.0.

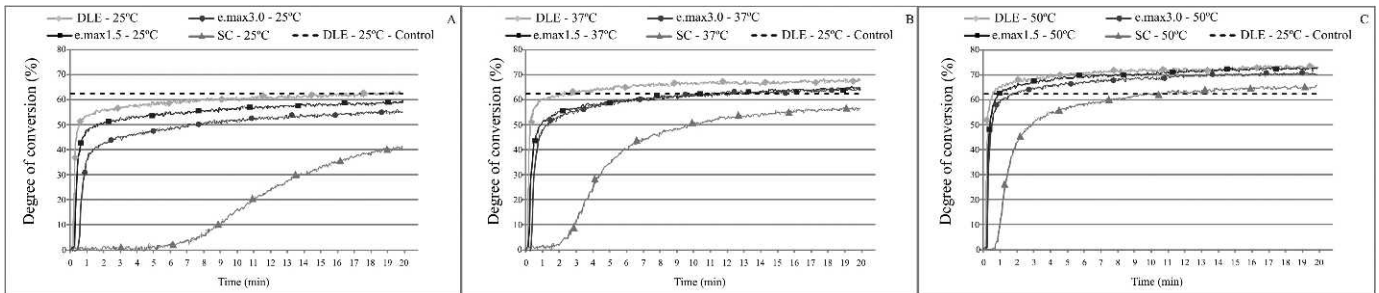


Figure 4. Polymerization kinetics of Variolink II at a 25°C (A), 37°C (B), and 50°C (C) exposed to four curing conditions. The dashed line represents the degree of conversion after light activation through a glass slide at 25°C. Thin ceramic disc: e.max1.5; thick ceramic disc: e.max3.0.

and 50°C (Figure 3C), the time-based conversion profiles appeared much more like that of the DLE group when exposing through the different thicknesses of ceramic discs as well as when the material was allowed to self-cure.

On the other hand, the conversion profile of Variolink II (Figure 4) was seen to depend mostly on the ability of the curing light to reach the resin cement layer in order to provide similar DC to that observed in the DLE group at 25°C. At that temperature (Figure 4A), it can be seen that the time-based conversion profiles, when shining curing light through either thickness of ceramic disc, appear much more like that of the group receiving DLE. The self-cure reaction appears to be very slow and does not reach the conversion levels after 20 minutes that the other groups did. At 37°C (Figure 4B), little difference is seen in the conversion profiles when using either thickness of ceramic. The rate of conversion increase with time for the self-cure mode increased over that seen at 25°C but is still less than other conversion values after 20 minutes. At 50°C, there is very little distinction in conversion profiles of the DLE group, and those polymerized through either thickness of ceramic. Conversion values for the self-cure group appear to be much greater than when at previous temperatures and finally approach DC values seen for the DLE group when polymerized at 25°C. As seen with specimens from Calibra, those from Variolink II polymerized at 50°C are well above the DC value of the respective DLE group at 20 minutes.

Working Time

For statistical analysis of WT data, the study was adequately powered for both factors, temperature and product (over 99%;  $\alpha=0.05$ ). The WT values of both resin cements in the self-cure mode at different temperatures are displayed in Table 3. The ANOVA indicated that the interaction between both temperature and product ( $p=0.00001$ ) significantly influenced WT. A significant decrease (73%) in the WT of Calibra was seen when the temperature increased to 37°C from 25°C, while no significant difference was noted increasing polymerization temperature from 37°C to 50°C, although the WT was noted to decrease by 90%. For Variolink II, significant decreases of 69% and 88% were observed in WT when resin cement temperature increased to 37°C and 50°C, respectively, compared to that at 25°C. Variolink II exhibited longer WT than Calibra regardless of temperature.

Table 3: Working Time in Seconds (Standard Deviation) of Calibra and Variolink II Polymerized at Three Temperatures<sup>a</sup>

	Calibra	Variolink II
25°C	83.4 (7.4) Ab	311.4 (80.7) Aa
37°C	22.5 (10.0) Bb	95.3 (31.0) Ba
50°C	10.1 (4.2) Bb	36.7 (5.3) Ca

<sup>a</sup> Significant differences are indicated by different letters (uppercase letters within column; lowercase letter within row) according to Tukey post hoc test at a preset alpha of 5%.

DISCUSSION

The research findings validated the first research hypothesis, which anticipated that dual-cured resin cements polymerized at either 37°C or 50°C will demonstrate higher DC than the same products polymerized at room temperature, even when the curing light is attenuated by the presence of indirect ceramic restorations with varying thickness or even when no curing light is available. Data seen in Table 2 provide strong evidence to support these statements. In contrast to light-cured-only resin composites, dual-cured resin cements contain not only photoinitiators but also self-curing components, such as benzoyl peroxide. Since the degradation rate of benzoyl peroxide into radicals increases with increased temperature,<sup>33</sup> radicals are created more rapidly when heated. Thus, the increase in DC observed in both resin cements to values as high as those observed in the DLE groups at 25°C could also be attributed to the higher amount of these radicals being created in the early stages of polymerization. These increases occurred even in conditions simulating clinically unfavorable environments, such as when a thick indirect restoration is interposed between the curing unit tip and the underlying resin cement layer.

Despite the well-reported severe attenuation in light intensity caused by the presence of indirect restorations between the resin cement layer and curing unit tip,<sup>3,14</sup> both resin cements exposed through 1.5 mm of overlaying ceramic at 25°C showed DC values as high as those observed in DLE groups after 20 minutes. These results are in agreement with those reported by others<sup>3,14</sup> who demonstrated that use of indirect restorations with thickness lower than 2 mm does not compromise DC of selected dual-cured resin cements. Based on the analysis of time-based conversion of Calibra at 25°C

(Figure 3A), the importance of self-curing components to compensate for lower light levels reaching the resin cement was evident, as a significant increase in conversion value with time was noted after light exposure in both the 1.5- and the 3.0-mm ceramic disc thickness groups. On the other hand, the light-curing components in Variolink II responsible for compensating for light attenuation were seen to work more effectively than in Calibra. For example, at 25°C, the conversion-based profile using a 1.5-mm-thick ceramic disc produced nearly the same result as the unattenuated DLE group.

A unique aspect of the current study was the inclusion of clinically relevant methods to attenuate the light-curing unit from providing radiant energy as an initiator for the photoactivated aspect of the dual-cure resins tested. Thus, a range of light availability was devised from no attenuation (DLE), through two different thicknesses of a commonly used ceramic material (1.5 or 3.0 mm in height), or the products were allowed to polymerize totally in the dark (self-cure only). Differences in the findings emphasize how commercial products vary in their ability to achieve high levels of conversion using either mode of polymerization activation. Calibra appears to be activated mostly by its self-curing components (Figure 3A), while Variolink II seems to be most effectively cured when receiving light (Figure 4A). Thus, one cannot make generalized statements about the overall ability of dual-cure cements to perform well in either type of curing mode. The differences in abilities of the different curing modes was somewhat overcome when resins were preheated compared to their use at room temperature. However, even when polymerization occurred at 50°C, the self-cure reaction of Variolink II still lagged behind the other groups.

It should be noted that the temperature spans tested are clinically relevant. These products are designed to be proportioned and mixed at room temperature and then placed against a freshly prepared tooth surface. Although many researchers feel that the prepared tooth surface is at body temperature (37°C), as tested in the current work, instead it is more between 27°C and 30°C.<sup>34</sup> Use of the 50°C temperature was applied in an attempt to see if the shortcomings of differences in light- and self-cure reactions could be overcome with preheating. Use of this temperature is well within those applied clinically, as composite is preheated and placed at temperatures well above this value: 68°C (Calset Composite Heater, AdDent Inc, Danbury, CT, USA). Interestingly, reduced exposure times are

advocated with use of the preheating device, as previous work has shown that elevated temperatures cause enhanced conversion levels when using less-than-recommended exposure times.<sup>24</sup> It is thought that the increased monomer and radical mobility conferred by lower system viscosity from the heated material is responsible for these more rapid curing and higher converted systems.<sup>24</sup>

In the current study, the effects of temperature were also evaluated with respect to the clinically relevant aspect of WT. This parameter is of importance because, if WT is reduced to the point the material becomes impossible to handle because it sets so rapidly, then little benefit would be gained by enhancing conversion as a result of preheating.

The second research hypothesis anticipated that a significant decrease in WT would occur when the temperature during polymerization was increased to either 37°C or 50°C over that seen at room temperature (25°C) for either product and was only partially upheld by the data. Table 3 indicates that the WT of each product decreased with increasing polymerization temperature; however, there was no significant difference between WT values for Calibra between 37°C and 50°C. At 25°C, Calibra exhibited a WT of approximately  $83 \pm 7$  seconds, while the value of Variolink II was much longer and much more variable at  $311 \pm 81$  seconds. This difference might be attributed to the formulation between the products: concentration of polymerization inhibitors and benzoyl peroxide. According to the material safety data sheet information, Calibra contains approximately 2% benzoyl peroxide, while Variolink II has approximately half that amount (1%). For this reason alone, the better self-curing capability of Calibra over Variolink II may be explained.

Other studies have found that elevated resin temperatures may reduce WT,<sup>25,26,35</sup> even to intervals that are not clinically useful. In the current study, reduction in WT of Calibra from 83 seconds at 25°C to 23 seconds at 37°C and then to only 10 seconds at 50°C might compromise the seating of indirect restorations and the success of the restorative procedure as a consequence. Based on this result, it seems that preheating of resin cements with higher content of self-curing components should be avoided. Significant reduction in WT was also observed for Variolink II: from 311 seconds at 25°C to 95 seconds at 37°C and 37 seconds at 50°C. Although use of Variolink II at 50°C led to a clinically unfavorable WT of 37 seconds, the use of this resin cement at a temperature close to that of the oral cavity (37°C) led to a WT of 95 seconds, falling within the time range



considered by manufacturers as acceptable for clinicians to seat the indirect restoration.

Future studies simulating the clinical condition are required to evaluate the effects of preheating dual-cure cement temperature on mechanical properties and bond strength. In addition, studies need to be performed to measure the actual temperature value of preheated dual-cure cements when they are placed against freshly prepared teeth *in vivo*. With the teeth being much cooler than the heated cements, a dramatic decrease in cement temperature may result, negating the anticipated enhanced properties of increased conversion and decreased WT. Only selected dual-cure resin products were tested in the current work, and thus the results do not present the effects of the wide range of composition variation among these products. However, the two products selected, showing clear distinctions in their differing ability to utilize either the light- or the self-cure polymerization reactions, do clearly indicate the need for clinicians to be aware of differences among the commercial products available.

### CONCLUSION

Within the limitations imposed by the current study, the following conclusions may be made:

1. Preheating dual-cured resin cements results in elevated monomer conversion values, even in a very inaccessible light-curing situation.
2. Increased resin cement temperature compensated for the lower radiant energy delivered from the light-curing unit caused by the presence of indirect restorations with varying thicknesses.
3. The WTs of dual-cure resins can be significantly decreased as a result of preheating, often leading to extremely rapid reactions, that would make clinical use of such a heated product inadvisable.

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### Conflict of Interest Declaration

The Authors of this manuscript certify that they have no proprietary, financial or other personal interest of any nature or kind in any product, service and/or company that is presented in this article.

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