In Vivo Temperature Measurement: Tooth Preparation and Restoration with Preheated Resin Composite

FREDERICK A. RUEGGEBERG, DDS, MS*
MÁRCIA DARONCH, DDS, PHD†
WILLIAM D. BROWNING, DDS, MS‡
MARIO F. DE GOES, DDS, MS, PHD§

ABSTRACT

Statement of the Problem: Composite preheating has shown to improve material physical properties in vitro, but no data exist on the use of this technique in vivo during placement.

Purpose: The study aims to measure in vivo prepared tooth surface temperature during a restorative procedure using resin composite either at room temperature (23.6°C) or preheated to 54.7°C in a commercial compule heating device set to heat at 60°C.

Methods: Class I preparations ($N = 3$) were made on a patient requiring multiple posterior restorations. A probe containing two thermocouples was used to record temperature values at the tooth pulpal floor and 2 mm higher (top of the tooth preparation/restoration) after tooth preparation (prep), acid etching (etch), placement and curing of a bonding agent (BA), and during placement of composite used at room temperature (RT) or preheated in a commercial device (Calset™, AdDent Inc., Danbury, CT, USA) set to 60°C. Data were compared with two-way analysis of variance, Tukey–Kramer post hoc test ($\alpha = 0.05$).

Results: No significant difference in pulpal floor temperature existed between prep (27.8° ± 1.3°C) and etch (26.3° ± 1.3°C), which were significantly lower than BA (30.5° ± 1.3°C) ($p = 0.0001$). Immediate placement of preheated composite resulted in significantly higher pulpal floor (36.2° ± 1.9°C) ($p = 0.0025$) and top composite temperatures (38.4° ± 2.2°C) ($p = 0.0034$) than RT values (30.4° ± 2.2°C and 29.6° ± 0.9°C, respectively).

Conclusions: In vivo use and placement of preheated resin composite resulted in temperature increase of 6° to 8°C than room temperature material. These values, however, were much lower than expected.

*Professor, Dental Materials Section, Department of Oral Rehabilitation, Medical College of Georgia, Augusta, GA, USA
†Research Scientist, Department of Pediatric Dentistry, New York University College of Dentistry, New York, NY, USA
‡Professor and Indiana Dental Association Endowed Chair in Restorative Dentistry, University of Indiana School of Dentistry, Indianapolis, IN, USA
§Professor, Department of Restorative Dentistry, Dental School of Piracicaba at UNICAMP, Piracicaba, São Paulo, Brazil

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CLINICAL SIGNIFICANCE

Although having many potential benefits, composite preheating may not be as clinically effective in delivering resin of predetermined temperature at the time of cure as laboratory experiments would suggest. Despite only moderate composite temperature increase over use of room temperature material, preheating still provides advantages in terms of ease of handling and placement.

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INTRODUCTION

The warming of dental resin-based products prior to placement into a tooth preparation was recently proposed.[1,2] Preheating is accomplished with placement and storage of restorative composite compules or syringes into a heating device. The use of this technique may facilitate ease of composite extrusion as well as enhance material adaptation to preparation walls over that currently observed when resin composite maintained at room temperature is used.[3,4]

The effect of preheating resin systems has many potential benefits. The flow of commercial resin composites can greatly increase upon preheating.[5] However, the extent of flow varies among brands and resin composite classifications, but the decrease in viscosity offered by preheated resin composite never reaches the low levels of a room temperature, flowable composite.[5] The overall extent and rate of monomer conversion in model, unfilled resin systems polymerized at higher temperatures are enhanced over those when performed at room temperature.[6–10] Recent in vitro studies using commercial resin composites indicate a significant increase in conversion upon increasing curing temperature, as well as an increase in both polymerization rate and conversion seen at maximum cure rate.[6,11,12] The resulting preheated material reaches higher monomer conversion with less applied energy dose, allowing reduction of exposure duration of up to 75%.[6]

Previous studies show no effect on monomer conversion when repeated or extended preheating cycles are applied to commercial resin composites,[13] meaning that there is no degradation of resin components at the temperature used for preheating. Furthermore, less than 1.0°C rise in in vitro intrapulpal temperature is observed when using composite preheated to 60°C compared with values of composite at room temperature.[14] However, composite temperature quickly decreases once a syringe or compule is removed from the heating device and its contents are injected into a tooth preparation.[13] The main issue when working with prewarmed composites is to maintain temperature once composite is removed from the heater base unit. Depending on the rate at which composite cools when placed into a tooth preparation in vivo, any potential clinical gain from warming could be lost, or reduced.

The sublingual temperature of humans is near 37°C for most healthy individuals.[15] This value is routinely used as an indicator of intraoral temperature, but one cannot assume that this value represents temperature in all locations within the oral cavity. Intraoral temperature depends on diverse factors, such as body temperature, room temperature and humidity, ingestion of hot and cold substances, smoking, and lip positioning (whether the mouth is open or closed).[15,16] Intraoral temperature varies considerably during a 24-hour period, and can range from 5.5 to 72.5°C.[15,16]

Tooth temperature during restorative treatment may change as a

function of restorative steps performed. The in vivo tooth surface temperature change during a clinical operatory sequence has not yet been reported. Although cavity preparation and light-curing may increase tooth temperature, water rinsing and drying may lower it.[17,18] While laboratory studies show improved composite physical properties with preheating, no data are available regarding the actual in vivo temperature change when using preheated or room temperature composite when contacting the prepared tooth in an actual clinical scenario.

The purpose of this study was to measure in vivo temperature changes during a typical sequence of restoration steps when delivering a photo-activated, resin-based, posterior composite restoration. The effect of inserting either prewarmed or room temperature composite at the pulpal floor as well as the top tooth surface was measured and compared during similar restorative stages. In addition, monomer conversion attained at each composite surface was estimated using previously acquired data from the same restorative material.

The research hypotheses tested were: (1) pulpal floor temperature values would be greater after placement and curing of a dentin bonding agent than when only rinsed after acid etching; (2) pulpal floor and top composite surface temperature would be greater when using preheated composite compared with the room temperature control; and (3) calculated conversion values at the pulpal floor and top, exposed composite surfaces would be greater with preheated composite than those observed at similar surfaces when using the room temperature control composite.

MATERIALS AND METHODS

Patient Selection and Teeth Preparation

The research protocol and written informed consent were approved by the Medical College of Georgia Human Assurance Committee (HAC# 04-02-274) prior to data collection. A male adult volunteer, needing multiple posterior restorations, was selected and seen in three separate visits. At each visit, one posterior tooth requiring a Class I or Class II restoration was prepared. The subject was anesthetized and the tooth was prepared using a conventional high-speed handpiece with water irrigant. Tooth preparation and restoration occurred without rubber dam placement. Prior to definitive, final tooth preparation, the pulpal floor depth was approximately 2-mm deep, and surrounding dimensions were no less than 2.5 mm in diameter, to ensure use of approximately equivalent volume of resin composite placed throughout the study.

Temperature Measurement

A custom handheld temperature measuring probe was constructed of a plastic shaft through which the wires for two separate, special limit of error (1.1°C or 0.4%) K-type thermocouples ran (part # TT-K-30-SLE, Omega Engineering Inc, Stamford, CT, USA). One thermocouple junction was positioned at the probe tip, and the other was placed 2 mm higher (Figure 1). This design allowed for simultaneous temperature readings of both top composite surface and pulpal floor. The output of each thermocouple was directed through separate electronic cold junction compensators (Model MCJ, Omega Engineering). The signal leaving the compensator was fed to a 16-bit A/D converter (SMAD, Mark S. Nathanson, Inc., Cambridge, MA, USA) and then directed to a personal computer (Macintosh SE, Apple Computer, Cupertino, CA, USA) and collected in real-time at a rate of 10 data points/second, where software displayed as well as digitally recorded data (MacChrom V2.02, Mark S. Nathanson, Inc.).

Composite Temperature

A conventional, photo-activated hybrid resin composite (Esthet—X, shade A2, lot # 0006233, Dentsply/Caulk, Milford, DE,

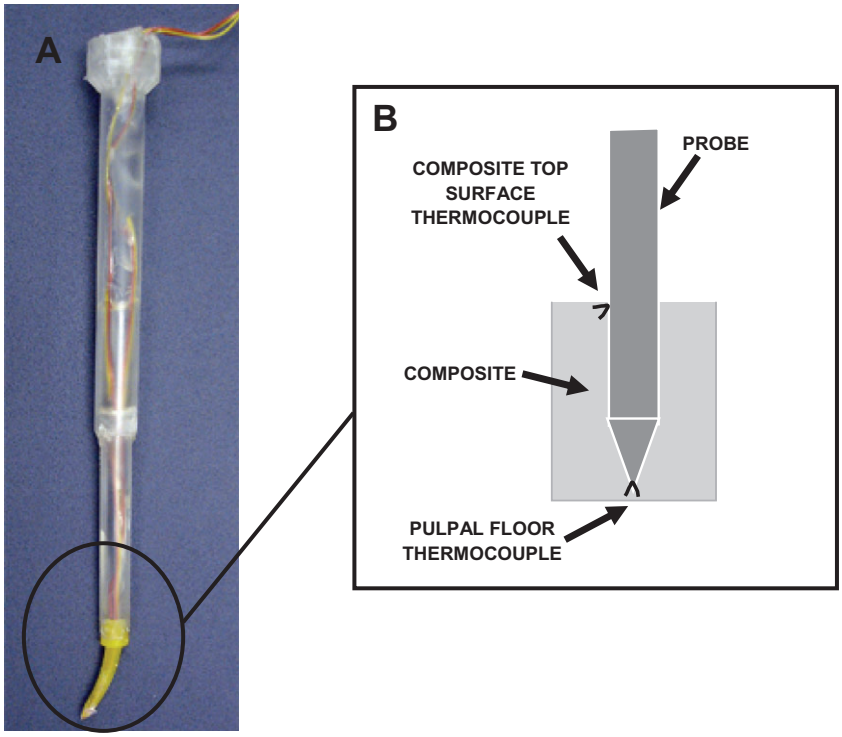

Figure 1. A, *Custom-made, hand-held temperature probe used for in vivo temperature measurement;* B, *Representative diagram showing measurement of intraoral composite temperature with the use of probe containing both K-type thermocouples.*

USA) was used in compule form. Compules were used when either at room temperature (23.6° ± 0.8°C) or when preheated in a commercial device (Calset™ AdDent Inc., Danbury, CT, USA) preset to 60°C. Previous work had identified that, when stored in the commercial device set to 60°C, the composite contents only reached an average of 54.7°C.[13] Composite compules were inserted into a syringe-like delivery device (Mark IIIp™ syringe, Centrix Dental Inc., Shelton, CT, USA). The loaded delivery device with compule was stored in the commercial preheater using the supplied syringe adapter. When needed, the syringe was obtained and the preheated composite was injected directly into the tooth preparation.

Temperature Readings and Restorative Procedure

Prior to data recording, the temperature of a beaker of water allowed to equilibrate to ambient levels overnight was measured using a high precision thermometer, traceable to NIST standards (pn 1516020, Fisher Scientific, Norcross, GA, USA). Using this method, the probe containing both thermocouples was calibrated to this known temperature at each visit prior to its use. Thermocouple millivoltage values generated at room temperature were adjusted to correspond to those developed when converting the thermometer readings into K-type millivoltage values. Recorded millivoltage data were converted into temperature values using standard thermocouple tables.[19] Once calibrated, the accuracy of readings with the range of interest (20–70°C) relying on correlation to the table gave a correlation coefficient of 1.000.

At each patient visit, temperature readings were taken at the pulpal floor for 20 seconds at each stage of the restorative treatment: following tooth preparation, after acid etching (Scotchbond™ etchant # 7523, lot # 3BJ, 3M-ESPE, St. Paul, MN, USA) and water rinsing; after placement of a 4th generation bonding agent (Optibond FL™ # 26684, lot # 307014, Kerr Corp., Orange, CA, USA) and curing for 20s (Optilux 501, Demetron/Kerr Co.); and during placement of either room temperature or preheated composite. In the last step, both top composite surface and pulpal floor temperatures were recorded simultaneously using the two thermocouples on the probe. The resin composite was not light-cured.

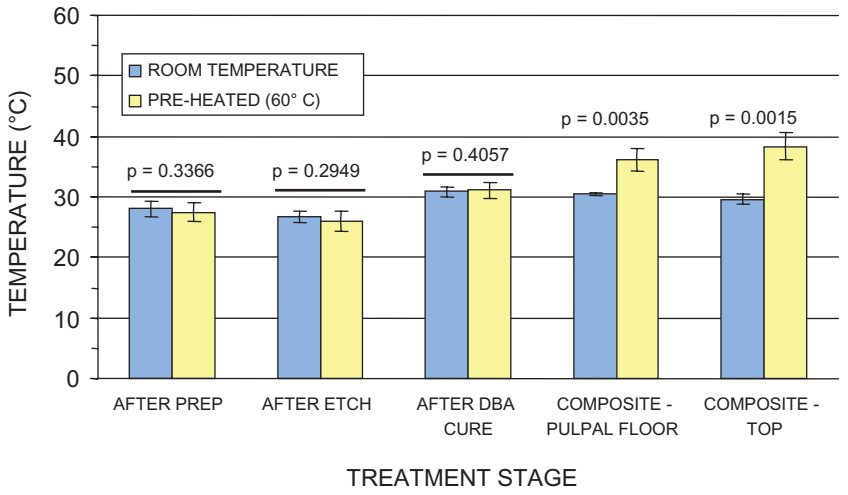

*Figure 2. Pulpal floor and composite top temperature changes during restoration stages of room temperature or preheated composite in vivo.*Vertical bar = ± 1 SD. *Each group represents the average of three repetitions, in which three separate temperature measurements were taken.*

Temperature values were determined 10 seconds after the probe touched the tooth surface, which was the time needed to stabilize millivoltage values. Thermocouple response time was measured to be 43 ms. Following temperature readings, the uncured composite was removed, the preparation walls slightly enlarged to ensure removal of the polymerized dentin bonding agent (DBA) and exposure of fresh dentin, and the said sequence was repeated two more times on the same tooth. Following removal of uncured composite from the last of the three insertion replications, the final preparation dimensions were established. Those ultimate preparation dimensions were no larger than would have occurred had prior, partial removal had not been made. The tooth then received a definitive restoration using the same restorative material (same lot) previously mentioned.

Monomer Conversion

The temperature recorded at the time at which light-cure would typically occur (10 seconds from placement) was used to calculate the likely composite monomer conversion. Data obtained from the same material (lot # 030221) tested isothermally at various temperatures in a previous study were used to make these calculations.[6]

Statistical Analyses

The three repetitions of temperature readings for each restorative treatment stage during a single visit were averaged and recorded as a single value. The values were then averaged for similar stages using data from each of the three different patient visits. Two-way and one-way analysis of variances (ANOVAs) were performed among and within temperature values of different composite temperatures and restorative stages, using the Tukey–Kramer post hoc test for pair-wise comparisons at a preset α of 0.05. Calculated conversion values were analyzed using a two-way ANOVA, with the major factors being composite temperature and depth (pulpal floor and top surface). The Tukey–Kramer post hoc test was again used for pair-wise comparisons at a preset α of 0.05.

RESULTS

The recorded temperature after each restorative stage for both room temperature and preheated composite groups is shown in Figure 2. The results of the two-way ANOVA indicated no significant effect of composite temperature ($p = 0.6155$), which was expected because at this point, no composite had been injected: temperature values were obtained only on the prepared teeth in the two different groups. Significant differences were noted, however, in temperature measurement values at the different restorative stages ($p = 0.002$), with an interaction term not demonstrating significance ($p = 0.8203$). No statistical difference was detected between the two composite temperature

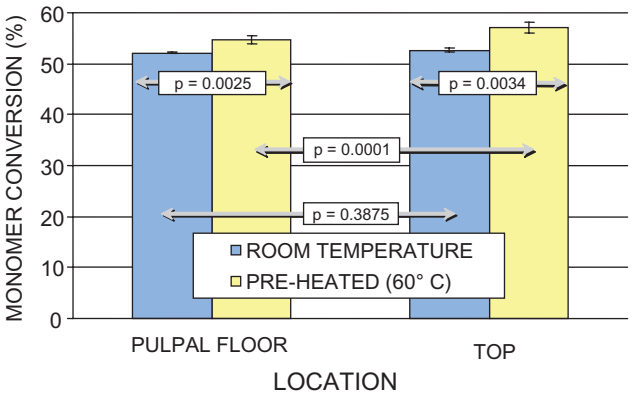

Figure 3. Calculated monomer conversion for top and bottom composite surfaces when either room temperature or preheated composite was placed and ready to be light-cured. Vertical bar = ± 1 SD.

groups when measuring the pulpal floor temperature after tooth preparation, acid-etching and water rinsing, or after DBA placement and light-curing. Grouped temperature values ($N = 6$) were as follows: 27.8° ± 1.3°C after tooth preparation, 26.3° ± 1.3°C after acid-etching and water rinsing, and 30.5° ± 1.3°C after DBA placement and light-curing.

Pulpal floor temperatures following placement and light-curing of the DBA were significantly higher than those seen after the tooth preparation or etching/rinsing stages ($p = 0.0001$), which were not different. Pulpal floor temperature following photocuring of the DBA was not significantly different from values at both composite surfaces when placing room temperature composite.

The results of the two-way ANOVA for measured composite temperature during the insertion phase of tooth restoration indicated a significant influence of composite temperature (room temperature or preheated temperature) ($p = 0.0001$), but no significant influence of temperature location (pulpal or top surface) ($p = 0.4613$), and no significant interaction term ($p = 0.1316$). Upon composite insertion, temperatures measured at the pulpal floor and composite top surfaces were significantly greater (6 and 8°C, respectively) when using preheated composite than when using the room temperature control. Composite temperature at the pulpal floor was 30.4° ± 0.3°C (for the room temperature material) and 36.2° ± 1.9°C for the preheated material. At the top composite surface, room temperature material was 29.6° ± 0.9°C while that of the preheated product was 38.4° ± 2.2°C. No significant difference in preheated composite temperature values between that of the pulpal floor and top surface ($p = 0.0988$) was found.

Calculated monomer conversion values attained at the temperatures recorded in vivo after placement were determined from the following equations based on the known temperature/conversion relationships of the same restorative material lot that had been established in a previous study[6]:

$$\text{Top surface: } y = 0.004x^2 + 0.778x + 33.140;\ r^2 = 0.999 \quad (1)$$

$$\text{Bottom: } y = 0.005x^2 + 0.876x + 29.044;\ r^2 = 0.998 \quad (2)$$

where x is composite temperature during polymerization and y is percent monomer conversion (Figure 3).

Composite monomer conversion values calculated for the in vivo temperatures recorded were as follows: 51.1 ± 0.2% (bottom, room temperature), 54.2 ± 1.0% (bottom, preheated), 52.7 ± 0.5% (top, room temperature), and 57.1 ± 1.1% (top, preheated). The two-way ANOVA indicated

significant differences in conversion between the two composite temperatures (room temperature and preheated) ($p = 0.0001$) at both depths (top and bottom) ($p = 0.0075$), but their interaction had no influence ($p = 0.0536$) (Figure 3). Conversion values of the preheated material were significantly higher than those of room temperature composite. Calculated conversion values at the top surface for preheated composite were significantly higher than those at the pulpal floor ($p = 0.0034$).

DISCUSSION

This investigation presents a novel method for measuring in vivo tooth temperature during a clinical procedure. Use of a custom-made, handheld probe, allowed tooth temperature to be immediately assessed after every stage of the restorative treatment, and during insertion of composite delivered at different temperatures. Baseline room temperature was 23.6° ± 0.8°C. The first temperature reading (27.8° ± 1.3°C) was taken at the pulpal floor after tooth preparation with a high-speed handpiece and a diamond bur, under constant water cooling. A second temperature reading (26.3° ± 1.3°C) was taken after acid-etching and water rinsing. Both values were significantly lower than when temperature was taken after placement and photocuring of a dentin bonding agent. Therefore, the first hypothesis was accepted. Although bur friction to the tooth surface will generate heat, adequate water cooling will maintain or even decrease tooth temperature.[17,18] Also, because of water rinsing, tooth temperature decreased after the acid-etching procedure. This finding may be different, however, with the use of self-etching agents, as they do not require a separate rinsing step. The higher temperature values seen after placement and curing of the dentin bonding agent were probably produced during photopolymerization. It is well documented that light-curing will produce heat generation, with potential increase of intrapulpal temperature values.[18,20,21] Results from the present work were found to corroborate those findings.

Temperatures measured at the pulpal floor and at the composite top surface were significantly greater when using preheated composite than when using room temperature material. Temperature did not change as expected, and a difference of only 6°C (pulpal floor) to 8°C (top surface) was seen shortly after the time of insertion. Notwithstanding the small variation in temperature between the two groups, a statistical difference was detected for the modest increase in temperature values when using preheated composite over that of the similar material at room temperature. For that reason, the second hypothesis was accepted.

Delivered in vivo composite temperature values were not near those of the heating device. Before insertion, there was a 31.1°C difference between room temperature (23.6°C) and measured composite temperature (54.7°C)[13] when stored in the Calset™ unit at the 60°C setting. But as the preheated composite was injected into the tooth preparation, the maximum temperature recorded was only 38.4°C (instead of 54.7°C) at the top surface, as opposed to 29.6°C when composite was maintained at room temperature. Likewise, at the pulpal floor, temperature was 36.2°C at the top surface when using preheated composite, as opposed to 30.4°C when composite was at room temperature.

Warmed composite lost heat quickly once removed from the Calset™ and inserted into a tooth preparation. The same effect was observed in a previous in vitro investigation: large temperature drop in a short period, with preheated composite time never reaching Calset™ preset temperatures, but rather varying from 55 to 59°C.[13] The rate of composite temperature change depends on thermal properties of the composite material, such as thermal diffusivity (the transient temperature change within a material when the

material is exposed to an environmental temperature stimulus).[22] Upon delivery, preheated composite undergoes a cooling effect, as material is achieving thermal equilibrium with the surrounding tooth structure, which, in this study, was found to be near 30°C prior to composite placement. Other factors, such as tooth position, cavity depth, and volume of composite used may also vary temperature gradients.

As the tooth structure was at a lower value than the preheated composite, the tooth acted as a heat sink, rapidly lowering composite temperature. Just the opposite happened with use of room temperature composite: as the material was at room temperature (23.6°C) and the tooth was at a higher temperature (near 30°C), composite temperature increased during insertion, with the pulpal floor at 30.4°C and the top composite surface at 29.6°C.

The recorded temperature at the pulpal floor was unexpected and interesting to note, and a major finding of this study. This temperature was not 37°C as generally assumed (intraoral temperature), but greatly cooled (30.5°C), and would act to rapidly cool warmed composite and instantaneously increase its viscosity and reduce the potential for composite flow and enhanced composite adaptation to prepared tooth surfaces. Different temperatures may be observed for different types and sizes of tooth preparation.

The third hypothesis was accepted: calculated conversion values at the pulpal floor and at the top, exposed composite surfaces were greater using preheated composite than when using the room temperature control material. A 2 to 4% increase in monomer conversion was associated with delivering preheated composite in vivo. These values are much less than those reported for the same material when composite was cured isothermally.[6] In a previous study, isothermal 60°C preheated composite yielded an increase of up to 99% in monomer conversion values compared with those at room temperature. Composite was not light-cured in this in vivo study. Because photopolymerization increased pulpal floor temperature, the temperature loss of preheated composite might have been less than if that surface had not been warmed by light application.

When comparing top and bottom calculated conversion values using preheated composite, the pulpal floor values were less than those at the top surface. Composite at the pulpal floor possibly cooled more rapidly when it touched the colder tooth surface. Thus, the temperature at this location is lower than that of the top, and the resulting conversion would be less. Although small, the increased conversion at the top surface relative to that of the room temperature control may provide greater wear resistance for the final restoration.[23] Although extrapolating measured temperatures to conversion values found in a previous study is a possible exercise, the use of theoretical measurements for degree of conversion should be interpreted with caution because only one type of composite was studied, and therefore such temperature/conversion relationships may not hold for other composite types, shades, or viscosities.

Because only one subject was examined in this study, a variation in temperature values may be seen in other populations because of age, gender, or ethnicity. However, it is expected that the general trends observed are applicable to other patients.

This in vivo study indicated that temperature of composite preheated using the 60°C preheating setting remained only 6 to 8°C above intraoral temperature once it was injected. There was a slight increase in monomer conversion of preheated composite compared with that of room temperature material, but not as much as seen with isothermal in vitro findings. Considering the in vivo temperature observed, a reduction in

light exposure duration is not recommended when working with preheated composites, as it may not yield a polymer with similar characteristics as those seen using a full exposure duration at room temperature. If an increase of preset temperature of the heating device as well as maintenance of composite temperature upon removal from the heater and placement in the preparation is achieved, a benefit from preheating may be realized. Until such conditions are met, the current preheating technique should be used, being aware of its limitations.

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Reprint requests: Frederick A. Rueggeberg, DDS, MS, Professor, Dental Materials Section, Department of Oral Rehabilitation, Section of Dental Materials, School of Dentistry, The Medical College of Georgia, Augusta, GA, 30912-1260. Tel.: (706) 721-3354; Fax: (706) 721-8349; email: frueggeb@mcg.edu

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