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In Vivo Pulp Temperature Changes During Class V Cavity Preparation and Resin Composite Restoration in Premolars

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Clinical Relevance

Pulp cooling due to the Class V preparation in premolars and subsequent to etch & rinse bonding has a protective effect against the heat generated during the resin composite exposure to the curing light, regardless of the restorative procedure.

SUMMARY

Objective: This *in vivo* study evaluated the influence of the sequence of all restorative steps during Class V preparation and restoration in human premolars on pulp temperature (PT).

Methods and Materials: Intact premolars with orthodontic extraction indication of 13 volunteers received infiltrative anesthesia and isolation with rubber dam. An occlusal preparation was made with a high-speed diamond bur under air-water spray until the pulp was minimally exposed, then a thermocouple probe was inserted within the pulp. A deep, 2.0-mm depth Class V preparation was made using a high-speed diamond bur under air-water spray. Three restorative techniques were performed (n=7): Filtek Z250 placed in two increments (10-second exposure,

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shade:A2, 3M ESPE, St. Paul, MN, USA), Filtek Z350 XT (40-second exposure, shade:A3D, 3M ESPE) and Tetric N Ceram Bulk Fill (10-second exposure, shade:IVA, Ivoclar Vivadent, Schaan, Liechtenstein), both placed in a single layer. Bonding layer and resin composite were exposed to light from the same Polywave LCU (Bluephase 20i, Ivoclar Vivadent). The peak PT and the difference between peak PT and baseline (ΔT) values were subjected to two-way, repeated measures analysis of variance (ANOVA), followed by the Bonferroni post-hoc test (α=0.05).

Results: Cavity preparation and etch & rinse procedures decreased the PT values ($p<0.001$). The 40-second exposure of Filtek Z350 caused the highest peak PT values (38.7±0.8°C) and the highest ΔT values (3.4±0.8°C), while Tetric N Ceram Bulk Fill showed the lowest values (-1.6±1.3°C; p=0.009).

Conclusion: None of the evaluated procedures resulted in a PT rise near to values that could offer any risk of thermal damage to the pulp.

INTRODUCTION

Restorative procedures incorporating the use of light activated resin composites (RC) are widely used. In order to optimize clinical procedures with minimal chairside time, LED light-curing units (LCUs) with irradiance values over 2000 mW/cm² are available.[1] In this context, *in vitro* studies evaluating restorative procedures using RCs on extracted teeth have shown temperature increases within the pulp chamber or under dentin disks close to or even higher than 5.5°C, a temperature rise considered harmful to the pulp.[2-4] Such an elevation in pulp temperature (PT) has been attributed mostly to heat caused by the curing light itself and partly to the influence of the RC curing exotherm.[5-8] Therefore, the PT rise is influenced by preparation depth, LCU type, incident irradiance, and distance from light tip to the target, as well as by the thermal and exothermic properties of the RCs themselves.[3,4,9]

Although such *in vitro* studies brought important knowledge about the impact of high power LED devices and RCs on PT, the effects of a restorative procedure incorporating the use of light-activated RCs and the use of air-driven handpieces with water irrigation on PT rise is much more complex. For instance, some studies show that cooling methods, such as air-water spray or only air spray when using slow- and high-speed handpieces, can reduce heat generated during cavity preparation.[10,11] Indeed, *in vivo* studies performed in dogs and humans indicate an average PT drop of 8.1°C and 5.8°C, respectively, after a Class V cavity preparation was made on the buccal surface using a high-speed diamond bur under constant cooling water.[12,13] Moreover, PT values continue to drop, even after the cavity preparation had been completed.[12] Based on this evidence, it should also be expected that rinsing off phosphoric acid when applying an etch & rinse adhesive system to a cavity preparation would maintain low PT values, despite the lack of any evidence regarding this aspect. As a consequence, it is reasonable to assume that the pulp would already be in a cooled state at the moment when the tooth is first exposed to a curing light, and heat caused by light during a restorative procedure would not be as high as previously shown.[14,15] However, to the extent of our knowledge, there is no literature showing the impact of all preparation and restorative steps performed on *in vivo* temperature changes in human pulp during a typical Class V RC restoration placement in premolars.

The purpose of this *in vivo* study was to evaluate the influence of the sequence of all clinical steps performed during preparation and restoration of Class V cavities in human premolar teeth on the real-time intrapulpal temperature: high speed, water-cooled, instrumentation, etch & rinse bonding procedure and light-curing, and insertion and photocuring of RCs. The research hypotheses tested were: 1) immediately following tooth preparation and following bonding procedures, PT values will be significantly lower than the baseline, physiological values (prior to tooth preparation); and 2) the levels of PT decrease resulting from cavity preparation and bonding agent procedures will not prevent PT values from increasing higher than the baseline temperature during restorative procedures using different products and filling/curing techniques.

METHODS AND MATERIALS

Thirteen patients (seven males and six females) requiring extraction of first premolars for orthodontic reasons were recruited from the local orthodontic specialization program. Patient inclusion criteria included: 1) treatment plans indicating premolar extractions for orthodontic reasons, 2) the presence of healthy, intact, non-carious, and non-restored, fully erupted treatment teeth, and 3) patients with well-controlled health conditions that allowed all procedures involved in the research to be performed with minimal risk. Exclusion criteria included: 1) those patients who did not agree to volunteer for the study. The subjects, ranging from 12 to 30 years, went through an initial clinical exam at the State University of Ponta Grossa clinics, after which the research methodology and study aims were explained. After informed consent was obtained, volunteers received both infiltrative and intraligamental injections using a local anesthetic (2% mepivacaine hydrochloride [36 mg], containing 1:100,000 epinephrine [18 microL]; Mepiadre, DFL Industria e Comercio, Rio de Janeiro, RJ, Brazil) when upper premolars were evaluated, while an inferior alveolar nerve block was used when procedures were performed on lower premolars.

The *in vivo* methodology to evaluate PT increase was described in previous studies,[12,16,17] and is illustrated in Figure 1. Prior to probe placement, two calibrated temperature probes were connected to a wireless temperature acquisition system (Temperature Data Acquisition-Thermes Wifi, Physitemp, Clifton, NJ, USA) and were kept immersed in 0.9% sterile saline solution at room temperature until pulp exposure was obtained. After receiving anesthesia and prior to the occlusal preparation and pulp exposure, the teeth were isolated with a rubber dam and a small amount of RC was bonded on the tip of the buccal cusp where the probe rested to adjust the probe position so the

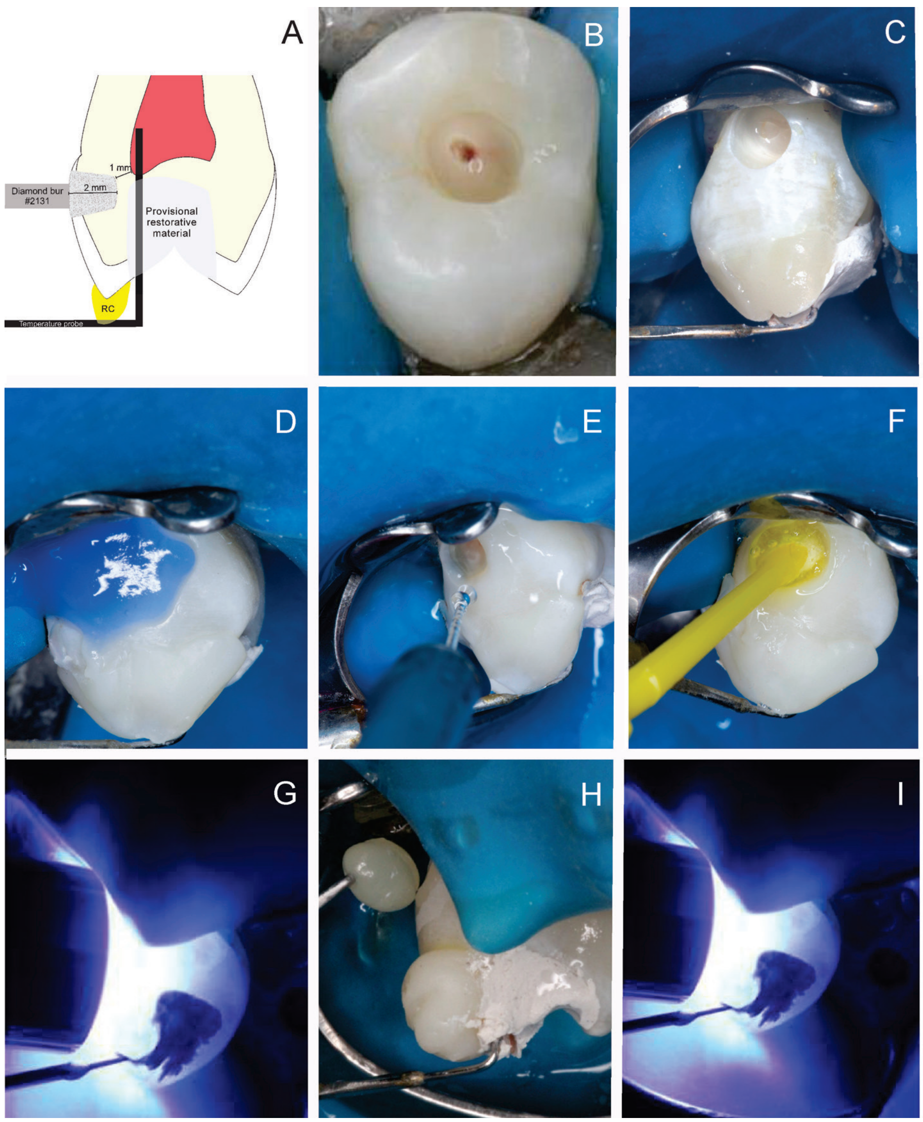

Figure 1. Representative images of temperature measurement in the dental pulp during restorative procedure and exposure to LED light. (A) Illustrative drawing showing the probe position and the shape of cavity preparation based on the diamond bur shape; (B) Deep, occlusal cavity preparation to produce a small pulp exposure; (C) Premolar with probe inserted into the pulp chamber through the occlusal cavity, sealed with a provisional restorative material and a deep Class V preparation; (D) Acid etching with 35% phosphoric acid gel; (E) Rinsing with water to remove acid; (F) Adhesive system applied according to the manufacturer's recommendations; (G) LED LCU tip positioned against the buccal surface of the tooth; (H) Increment of RC placed within the cavity preparation; (I) Polymerization of the RC layer.
Abbreviations: LCU, light curing unit; LED, light-emitting diode; RC, resin composite.

probe tip could be as close as possible to the axial wall of the buccal, Class V preparation (Figure 1A). A small, occlusal preparation was made in the center of the premolar, using a round diamond bur (#1015, KG Sorensen, Cotia, São Paulo, Brazil) in a high-speed handpiece, with controlled air-water spray, until the pulpal floor was near the buccal pulp horn. A pulp exposure small enough for only the probe to fit into the pulp chamber through the buccal pulp horn (Figure 1B), with no pulp bleeding, was carefully obtained using a small, pencil-shaped diamond bur (#2134; KG Sorensen). One probe was removed from the saline solution and inserted immediately within the pulp tissue through the access hole. The probe was positioned to remain stable in a small groove previously created on the top of the cusp tip. The probe remained at a pre-determined depth of approximately 4 mm within the pulp chamber, as close as possible to the axial wall of the buccal, Class V preparation, while PT was measured. The occlusal cavity was filled using a provisional restorative material (Cavitec, Caithec LTDA, Sao Jose dos Pinhais, PR, Brazil) to ensure probe stabilization and to reduce the heat that could dissipate through the cavity, as previously described (Figure 1A).[12,16] The other probe was maintained in the saline solution at room temperature (approximately 22.0°C) as a reference for validation of system operation. Room temperature was stabilized throughout the procedure, being controlled by air conditioning set to approximately 22°C. After probe stability was confirmed, real-time temperature data were continuously acquired for approximately 15 minutes, until a stable, baseline PT (approximately 35.3°C) was reached. Afterward, a controlled-size, Class V tooth preparation was made on the buccal surface (Figure 1C), using a diamond bur (#2131; KG Sorensen) in a high-speed handpiece with three water-emitting apertures (0.5 mm in diameter, Roll Air 3, KaVo Dental GmbH, Biberach, Baden-Württemberg, Germany), under controlled amounts of air-water spray (33 ml/min) at approximately 22°C. The preparation size was approximately 2.5 mm in diameter and 2.0 mm in depth, based on the bur dimensions, leaving approximately 1 mm thick dentin remaining between the axial wall and the pulp chamber (Figure 1A). A periodontal probe was used to confirm the preparation size of every cavity preparation.

In Vivo Restorative Procedures Using Light-activated RCs

Teeth were randomly assigned to groups according to the product (n=7). Manufacturer-recommended adhesive systems (Single Bond Universal, 3M ESPE, St Paul, MN, USA, and Tetric Nano Bond, Ivoclar Vivadent, Schaan, Liechtenstein) were applied and light-cured (Figure 1) according to the manufacturers' instructions (Table 1). In this regard, the Class V preparation was acid etched with 35% phosphoric acid for 15 seconds (Figure 1D), and the acid was removed with air-water spray for 15 seconds (Figure 1E). The bonding agent was applied according to the manufacturers' instructions (Table 1) (Figure 1F), and an air jet was gently applied to evaporate the solvent content until no adhesive accumulation was noticed. The adhesive layer was exposed to light curing for 10 seconds (Figure 1G) and the cavity was filled with RC composite according to each experimental group (Figure 1H). In order to simulate the effects of an incremental technique on PT values in a shallow cavity preparation such as that evaluated in the current study, Filtek Z250 (Shade: A2, 3M ESPE) was placed in two 1-mm thick increments, with each layer exposed to a dental curing light for 10 seconds (radiant emittance: 1230 mW/cm^2, Bluephase 20i, Ivoclar Vivadent). However, only PT values after the second exposure were compared to those obtained in the other products. A bulk-fill composite, Tetric N Ceram Bulk Fill (Shade: IVA, Ivoclar Vivadent), was placed in a single 2-mm thick increment, which was exposed to the same curing light for 10 seconds (Figure 1I). Finally, the cavity preparation was bulk filled (an approximtely 2-mm thick layer) with an opaque, darker shade composite comprising a longer, 40-second exposure following the manufacturer's instruction (Filtek Z350 XT, Shade: A3D, 3M ESPE) in order to observe pulp temperature change to an extreme in LCU exposure.

The PT values, expressed in Celsius degrees (°C), were obtained in real-time, every 0.2 seconds by a data acquision software program (DASYLab 11, Measurement Computing Corp, Norton, MA, USA). At the end of the analysis, the thermocouple probe was removed, and the teeth were atraumatically extracted. The probe was reinserted to simulate the intraoral position, and X-rays were taken to confirm placement as well as the thickness of the remaining dentin wall. The peak PT values during cavity preparation, bonding procedures, and exposure of bonding agents and RC to the curing light were recorded. In addition, the pre-preparation, physiologic baseline PT values were subtracted from the peak PT values to determine the PT range (ΔT) values during each restorative step. To determine the interval between each restorative step, the time into the data acquisition when each procedure was performed was recorded.

The radiant emittance values (mW/cm^2) of the LCU were obtained after spectral power analysis using a spectroradiometer (USB 2000, Ocean Optics,

Table 1: *Products, Manufacturer, and Instructions for Use*

Product Classification	Product (Shade)	Manufacturer	Composition (Supplied by Manufacturer)	Instructions for Use[a]	Filler Content/ Volume (%)
Dentin Bonding Agents	Single Bond Universal	3M ESPE	2-hydroxyethyl methacrylate; bisphenol A diglycidyl ether dimethacrylate (Bis-GMA); 2-propenoic acid, 2-methyl-, reaction products with 1,10-decanediol and phosphorous oxide (P2O5); ethanol; water; copolymer of acrylic and itaconic acid; camphorquinone; dimethylaminobenzoat(-4)	a; b	—
	Tetric N-Bond	Ivoclar Vivadent	Bis-GMA; ethanol; 2-hydroxyethyl methacrylate; phosphonic acid acrylate; urethane dimethacrylate; Aquatic Chronic 3, diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide;	a; c	—
Incrementally Filled Copmosites	Filtek Z350 XT (A3D)	3M ESPE	Silane treated ceramic; silane treated silica; urethane dimethacrylate (UDMA); Bisphenol A polyethylene glycol; Diether dimethacrylate; Bisphenol A diglycidyl ether; Dimethacrylate (Bis-GMA); Silane treated zirconia polyethylene glycol dimethacrylate triethylene glycol dimethacrylate	d	63.3
	Filtek Z250 (A2)	3M ESPE	Silane treated ceramic; Bisphenol a polyethylene glycol; Diether dimethacrylate (Bis-EMA); Diurethane dimethacrylate (UDMA); Bisphenol A diglycidyl ether; Bis-GMA; Triethylene glycol dimethacrylate (TEGDMA); Aluminum oxide	e	60
Bulk-Fill Composite	Tetric N-Ceram Bulk-fill (IVA)	Ivoclar Vivadent	Bis-GMA; UDMA; ytterbium trifluoride; Bis-EMA; Aquatic Chronic	f	61

Abbreviations: Bis-EMA, ethoxylated bisphenol-A dimethacrylate; Bis-GMA, bis-phenol A diglycidyl ether dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, diurethane dimethacrylate.

[a] a) Pre-condition with phosphoric acid (35 - 37 %) of enamel and dentin for 15 s, rinse and air-dry without dehydration; b) Apply the adhesive with a microbrush, rubbing for 20 s. Apply air jet for 5 s, light cure for 10 s (Bluephase 20i – High Power); c) Apply the adhesive with the aid of a microbrush, rubbing gently for at least 10 s. Apply air jet until no adhesive accumulation is noticed, light cure for 10 s (Bluephase 20i – low mode: 656 mW/cm^2); d) Apply increment of up to 2 mm, adapt with a spatula and light cure for 40 s (Bluephase 20i – High Power); e) Apply increment of 1 mm, adapt with a spatula and light cure for 10 s (Bluephase 20i – High Power); f) Apply increment of up to 4 mm, adapt with a spatula and light cure for 10 s (Bluephase 20i – High Power)

Dunedin, FL, USA) connected to a 6-inch integrating sphere (Labsphere, North Sutton, NH, USA). The measurement system was calibrated using a light source traceable to NIST standards. The LCU tip end was positioned at the entrance of the integrating sphere, so all light emitted from the unit was captured. Wavelength-based, spectral power emission was recorded between 350 nm and 550 nm using software (SpectraSuite v2.0.146, Ocean Optics), which also provided a total emitted power value for that wavelength range and the spectral emission profile as well (Figure 2). The optical emitting area of the distal end of the light guide was calculated, and this value was divided into the integrated spectral power value to derive the total radiant emittance.

Statistical Analyses

The homogeneity test of variances and Shapiro Wilk normality tests were performed for the dependent variables peak PT, ΔT data, and interval between procedures, with both parameters passing. Thus, the peak PT and ΔT values were subjected to two-way, repeated measures analysis of variance (ANOVA) (independent variables "product" and "restorative steps"), followed by the Bonferroni *post-hoc* test. The interval between each restorative step was compared among products using one-way ANOVA followed by the Tukey *post-hoc* test. All statistical testing and *post hoc* power analysis were performed at a preset α of 0.05, using commercial statistical software (Statistics 19, SPSS Inc., IBM Company, Armonk, NY, USA).

RESULTS

For the number of evaluated teeth (n=7), the *in vivo* study was adequately powered for both peak PT and ΔT values (above 99.0%; α=0.05), which are shown in Tables 2 and 3, respectively. Cavity preparation caused a significant drop in PT values ($p<0.001$), and a further decrease in PT values was also noted after the etch & rinse bonding procedures ($p<0.001$). A significant increase in PT values was observed after the bonding agent and after the resin composite layers were exposed to LED light ($p<0.001$). The 40-second exposure of Filtek Z350 (38.7±0.8 °C) caused the highest peak PT values ($p<0.001$), while the PT values after the exposure of the second layer of Filtek Z250 were not different from the baseline, physiological PT values. The PT values after the exposure of Tetric N Ceram Bulk Fill to curing light were still significantly lower than the baseline PT values ($p=0.002$).

The ΔT values were negative after LED exposure in most scenarios (Table 3). No significant difference in ΔT values was observed among products either after cavity preparation or after the bonding procedures. The 40-second exposure of Filtek Z350 to curing light caused the highest ΔT values (3.4±0.8°C), which were significantly higher than those after the 10-second exposure of Filtek Z250 (0.3±0.5°C) ($p<0.001$), which in turn showed significantly higher ΔT values than did Tetric N Ceram Bulk-Fill (-1.6±1.3°C; $p=0.009$).

Figure 3 shows the representative profiles of PT changes during the restorative steps. The drop in PT values during cavity preparation and etch & rinse procedures was observed in all groups. A slow

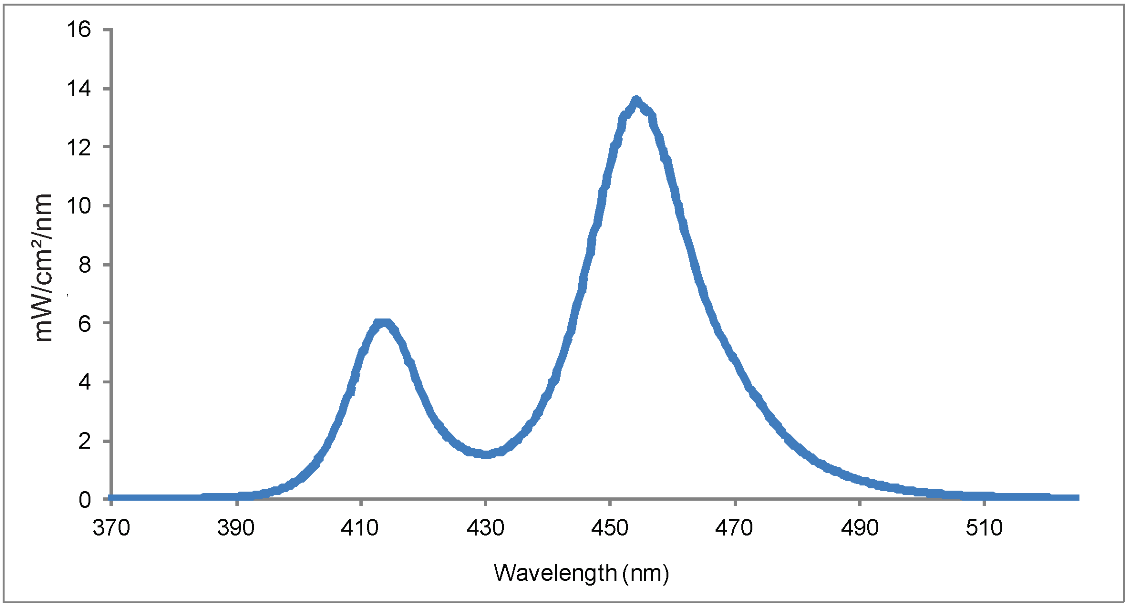

Figure 2. *Spectral emission profile of Bluephase 20i*

Table 2: *Mean (standard deviation) of* in vivo *pulp temperatures subsequent to specific restorative procedures*[a]			
	Filtek Z250 Two Increments 10 s	**Tetric N Ceram Bulk-fill One Increment 10 s**	**Filtek Z350 One Increment 40 s**
Baseline temperature	35.0 (0.6) Aa	35.1 (0.9) Aa	34.9 (0.7) Ba
Cavity preparation	29.8 (1.2) Ca	27.9 (1.8) Ea	28.2 (2.1) Ea
Etch-and-rinse bonding procedures	30.2 (1.1) Ca	29.6 (1.6) Da	29.8 (1.4) Da
Exposure of bonding agent to LED light	32.2 (1.0) Ba	31.1 (1.6) Ca	32.2 (1.1) Ca
Exposure of RC layer to LED light	35.6 (0.6) Ab	33.9 (1.5) Bb	38.4 (1.0) Aa

Abbreviations: LED, light-emitting diode; RC, resin composites.
[a] *Means followed by similar letters (lower case: within row; upper case: within column) are not significantly different (α=0.05).*

Table 3: *Pulp Temperature (°C) Range with Respect to the Pre-preparation, Physiologic Baseline Temperature (ΔT) After Curing Light Exposure at Three Restorative Moments into the Restorative Sequence*[a]			
	Filtek Z250 Two Increments 10 s Mean (SD)	**Tetric N Ceram Bulk-fill One Increment 10 s Mean (SD)**	**Filtek Z350 One Increment 40 s Mean (SD)**
Cavitypreparation	-5.3 (1.2) Aa	-7.2 (1.0) Aa	-6.8 (2.2) Aa
Etch & rinse bonding procedures	-4.9 (1.1) Aa	-6.0 (1.0) Aa	-5.4 (1.7) Ba
Exposure of bonding agent to LED light	-2.8 (0.8) Ba	-4.3 (1.1) Ba	-2.8 (1.1) Ca
Exposure of RC layer to LED light	0.3 (0.5) Cb	-1.6 (1.3) Cc	3.4 (0.8) Da

Abbreviations: LED, light-emitting diode; RC, resin composites.
[a] *Mean (SD) followed by similar letters (lower case: within row; upper case: within column) are not significantly different (pre-set α=0.05).*

PT increase was noted while the bonding agent was applied, followed by a small PT drop during the gentle airflow to evaporate the organic solvent. A quick but low rise in PT values was seen while the bonding agent layer was exposed to light curing. PT values increased rapidly during the exposure of RC layers to curing light. Small PT peaks were observed during short exposures such as a 10-second exposure (Figures 3A and 3B), while a higher PT peak was noted during the 40-second exposure (Figure 3C). When the Filtek Z250 was applied using the incremental technique and each RC layer was light-cured separately, the peak PT observed after the exposure of the first increment to curing light was apparently lower than that observed after the exposure of the second increment.

Figure 4 shows the comparison of intervals among products within each interval between restorative steps. Overall, no significant difference in most intervals between steps was noted among products. The interval between RC placement and light curing was shorter when Z250 was applied than when the preparation was filled with Tetric N Ceram Bulkfill (p=0.007).

DISCUSSION

To the extent of the authors' knowledge, this is the first *in vivo,* human study that evaluated the impact of PT drop caused by cavity preparation on the PT increase during restorative procedures with light-activated RCs. As previously shown *in vitro*[11] and *in vivo,*[12] cavity preparation under constant air-water spray caused a significant drop in PT values to approximately 29°C. A slow PT increase was then observed after cavity preparation, followed by another significant drop in PT due to the etch & rinse procedure (Figure 3). Therefore, the first research hypothesis was accepted. Although these results corroborate previous findings,[11,12,18] it is important to emphasize that heat production during cavity preparation depends on many factors, such as bur shape, type, and size; abrasiveness; wear of the diamond coating; pressure applied by the operator;

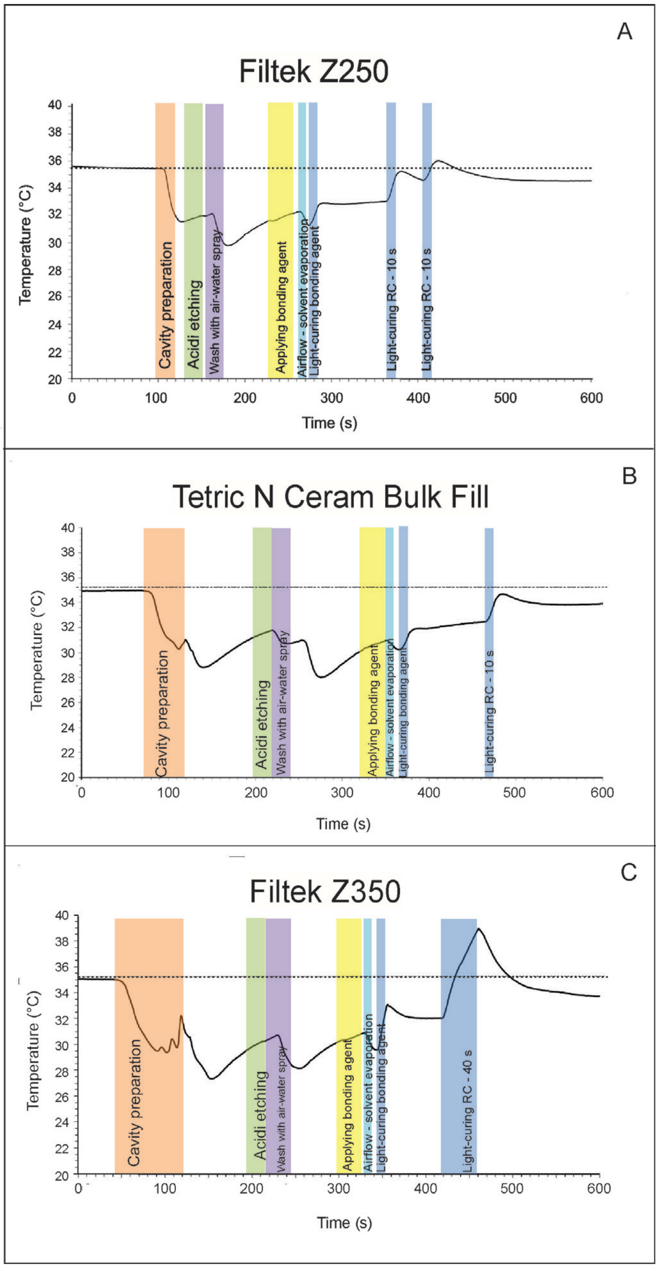

Figure 3. *Representative real-time profiles of PT changes during restorative procedures for each material examined: (A) Filtek Z250 (10 s); (B) Tetric N Ceram Bulk Fill (10 s; and (C) Filtek Z350 XT (40 s). Abbreviation: PT, pulp temperature.*

grinding time and rate; amount of debris clogging on the grinding surface; and speed and torque of the rotatory instrument.[18,19] However, it has also been shown that air-water spray has a major impact on the temperature within the pulp chamber when a high rate of air-water spray is applied.[11,18] Thus, water temperature[20] and flow rate[10] play an important role in controlling pulp temperature during tooth preparation. In this regard, the air-water spray used in the current study (33 ml/min) is within the range (30-50 ml/min) considered effective in reducing the temperature within the pulp chamber during the cavity preparation.[10,11] Therefore, because a high flow rate is applied, such outcomes should be expected, regardless of the bur type used.

Despite the increase in PT values after the etch & rinse procedure, due to the time lapse between that step and the subsequent light exposure of the bonding agent layer (Figure 4), the PT values were still lower than the baseline values, even after the first exposure of the bonding agent to curing light: approximately 32°C (Figure 3). In contrast to this finding, great concern has been shown by some authors as their results show that heat created during this step would be capable of inducing pulpal damage in deep preparations, due to the reported high temperature increase within the pulp when no RC layer was present to act as an insulator.[21-23] However, in those *in vitro* studies, the influence of cooling water during the cavity preparation or inclusion of an etch & rinse procedure, or the influence of airflow applied to evaporate the solvent were disregarded. Therefore, under clinical conditions, such as those used in the current methodology, light exposure of the bonding agent does not seem to offer any risk of pulp damage. Nonetheless, it is important to notice that the current methodology did not include the use of low-speed burs to remove caries, and only etch & rinse bonding agents were used. Because the use of low-speed burs without any cooling can increase PT to values near those considered harmful for the pulp[2,13] or even higher,[24] and the etch & rinse procedure is not applied when a self-etching bonding agent is used,[25] the current results should not be extrapolated to such other clinical scenarios. Further investigation is required to address those issues.

As clearly seen in the analysis of peak PT and ΔT values (Tables 2 and 3), only the 40-second exposure of Filtek Z350 increased PT to values exceeding the pre-preparation baseline PT, when high radiant exposure values were delivered (approximately 49.2 J/cm^2). Thus, the second research hypothesis was partially rejected. Such a great amount of energy delivered to an RC restoration is not usual in the daily clinical routine, as most manufacturers usually recommend shorter exposure intervals, such as 10 seconds or 20 seconds. The impact of the heat generated during an RC restoration on PT values depends on many factors: curing light irradiance, exposure time, RC properties (enthalpy of polymerization, thermal conductivity, density, heat capacity, reflectance, and light penetration depth), restoration size, amount of remaining dentin, presence of thermal barrier layers, and convective heat loss.[23] However, among these factors, the amount and

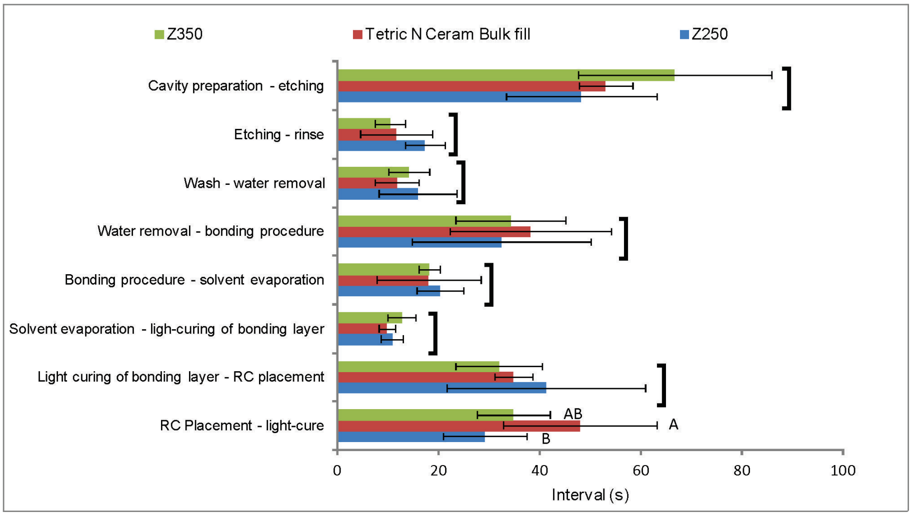

Figure 4. *Bar graph showing the average interval between restorative steps for each product. Means with different uppercase letters are significantly different (pre-set α=0.05). Means without significant difference are connected by brackets. Only comparisons among products within each interval were made.*

rate of the energy absorbed during irradiation have been considered the main factors for PT increase,[15,26] as also observed in this study. In addition, based on the current findings, the temperature of the tooth substrate and pulp also seemed to have a substantial impact on the influence of heat on PT values. In other words, any drop in dentin and enamel temperature due to the etch & rinse procedure[27] creates a gradient temperature between the cooled dentin walls and the pulp, so the cooled dentin acts as a heat sink that not only lowers the PT values but also absorbs some of the heat generated during light exposure, allowing the system to reach thermodynamic equilibrium. For this reason, a greater amount of energy, such as that delivered after 40-second exposure of Z350, was required to cause higher PT peak values than the physiological, baseline values, as noticed in the current study.

The influence of heat released from the RC layer has gained more attention with the introduction of bulk-fill RCs. Due to the exothermic nature of RC polymerization[28] and the greater volume of polymerizing composite when a thick layer of bulk-fill RC is placed within a deep cavity preparation, these resins generate more heat during light-curing than do conventional RCs.[14,29] Despite that aspect, no significant difference was noted in the peak PT values between teeth restored using Tetric N Ceram Bulk Fill and those restored using multiple thin increments of Filtek Z250. One could state that only a 2-mm thick layer of Tetric Ceram Bulk Fill was evaluated, so a greater volume of the bulk-fill RC would cause higher PT increase. In contrast to this assumption, previous research demonstrates that increasing the thickness of the RC layer resulted in a lower increase in temperature values within the pulp chamber.[30] The authors attributed those findings to the greater insulating effect provided by the thicker resin layers against the heat caused by the LCU. Thus, based on the current findings, the capacity of thicker RC layers to act as insulators and reduce the PT increase is greater than the influence of the heat from the exothermic polymerization on the PT values. Such a finding has also been seen *in vitro* when bulk-fill RCs were evaluated.[31]

Although the Class V preparations evaluated were considered deep because the axial wall was close to the pulp, cavity dimensions were not as large as those of Class I or Class II preparations. For this reason, the outcomes should not be extrapolated to those clinical scenarios, where multiple layers of resin composite and successive exposures to LCU are required. Moreover, because the thickness of remaining dentin plays an important role acting as a thermal insulator[32] due to its low thermal conductibility,[33] thicker or thinner remaining dentin layers could lead to different outcomes, as previously shown.[32] It should be also noticed that this study was conducted in young patients, so the evaluated premolars had larger pulp chamber volumes and higher pulp blood flow than do teeth of older patients.[34-36] Thus, the outcomes may vary according to the patient age. In addition, the current study was only performed on premolars, so differences in PT range may be expected in teeth with smaller or larger crown sizes. Therefore, caution should be taken when extrapolating these outcomes to clinical scenarios different from the one evaluated using this methodology.

CONCLUSION

Based on the limitations imposed by this *in vivo* study, it is possible to conclude that: 1) In the most clinically relevant scenarios, pulp chamber temperature decrease after cavity preparation prevented PT rise above the pre-preparation, physiologic baseline exposure conditions; 2) Longer exposure of a layer of resin composite to a high radiant emittance light curing unit caused higher peak PT and ΔT than did use of shorter exposure periods; and 3) None of the evaluated procedures resulted in a PT rise near to values that could offer any risk of thermal damage to the pulp.

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Regulatory Statement

This study was approved by the Ethics Committee of the State University of Ponta Grossa (protocol #1.954.754).

Conflict of Interest

The authors of this article 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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