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Controlling *In Vivo*, Human Pulp Temperature Rise Caused by LED Curing Light Exposure

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Clinical Relevance

In vivo pulp temperature rise during exposure of intact premolars to a high-powered LED light-curing unit can be prevented by applying air flow simultaneously with the exposure.

SUMMARY

Objective: The objective of this study was to evaluate the *in vivo* effectiveness of air spray to reduce pulp temperature rise during exposure of intact premolars to light emitted by a high-power LED light-curing unit (LCU).

Methods and Materials: After local Ethics Committee approval (#255945), intact, upper first premolars requiring extraction for orthodontic reasons from five volunteers received infiltrative and intraligamental anesthesia. The teeth (n=9) were isolated using rubber dam, and a minute pulp exposure was attained. The sterile probe from a wireless, NIST-traceable, temperature acquisition system was inserted directly into the coronal pulp chamber. Real-time pulp temperature (PT) (°C) was continuously monitored, while the buccal surface was exposed to a polywave LED LCU (Bluephase 20i, Ivoclar Vivadent) for 30 seconds with simultaneous application of a lingually directed air spray (30s-H/AIR) or without (30s-H), with a seven-minute span between each exposure. Peak PT values were subjected to one-way, repeated-measures analysis of variance, and PT change from baseline (ΔT) during exposure was subjected to paired Student's *t*-test (α=0.05).

Results: Peak PT values of the 30s-H group were significantly higher than those of 30s-H/AIR group and those from baseline temperature (p<0.001), whereas peak PT values in the 30s-H/AIR group were significantly lower than the baseline temperature (p=0.003). The 30s-H/

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AIR group showed significantly lower ΔT values than did the 30s-H group ($p<0.001$).

Conclusion: Applying air flow simultaneously with LED exposure prevents *in vivo* pulp temperature rise.

INTRODUCTION

Light-emitting diode (LED) light-curing units (LCUs) have become part of everyday clinical dentistry. The success of these devices is due to their efficiency and design, as they are battery driven and often do not require cooling fans. In addition, these LCUs are able to emit light with considerably higher radiant emittance values and have higher source longevity than do conventional quartz-tungsten-halogen lights (QTH).

Over the last decade, powerful LED LCUs have become commercially available to promote better polymerization of resin-based materials using shorter exposure durations. These devices are capable of emitting light with irradiance over 2000 mW/cm^2, and exposure times of no longer than five seconds are recommended by some manufacturers. As a consequence, these high-power LED LCUs generate heat in the target object.[1] In this regard, several *in vitro* studies report a significant temperature increase within the pulp chamber of extracted teeth, ranging from 1.5°C to 23.2°C.[2-8] Although this temperature range depends on LCU type, radiant emittance, and tooth characteristics,[3-12] there is a consensus that the use of some LED LCUs can result in a pulp temperature (PT) rise to values close to, or even higher than, the threshold temperature increase of 5.5°C, a value considered harmful to the pulp.[13] Most recently, a new *in vivo* methodology comprising the placement of a temperature probe within the pulp in human premolars has been developed.[14,15] Using this method, higher PT rise than 5.5 °C in intact premolars was observed as radiant exposure value increased.[15]

Heat control during restorative procedures to assure pulp integrity has been a great concern among clinicians and researchers.[13,16,17] For instance, several studies evaluated the effectiveness of alternative methods to reduce the heat caused during tooth preparation when using slow- and high-speed hand pieces and have shown it to be an effective method in reducing heat generated during that restorative step.[17-22] Other studies evaluated the use of different lasers instead of burs,[23-27] as well as the use of different cooling system protocols, including air and water spray from the triple syringe.[18,28-30] In addition, some cooling strategies have proven to be effective in reducing temperature rise within the pulp chamber during the debonding of orthodontic brackets[31] or during the fabrication of provisional restorations comprising the use of self-polymerized acrylic resins.[32] In this regard, different approaches have been suggested to reduce heat during the polymerization of resin composites, such as the use of reduced irradiance,[30,33] or discontinuous curing modes.[34] However, such procedures may compromise monomer conversion and impair the mechanical properties of the resulting resin composites.[35] To date, only one *in vitro* study demonstrated that cooling strategies comprising the use of air or the combination of air/water can reduce temperature rise during exposure of indirect restorations to curing light.[36] Another study showed that a cooling system installed in a LED LCU was effective in reducing the maximum temperature rise within the pulp chamber and speeding up the cooling process of the tooth after light shut off.[4] Based on these findings, it is reasonable to assume that the use of air spray would prevent PT rise *in vivo*, in human premolars, during exposure to the light emitted from a polywave LED LCU (Bluephase 20i, Ivoclar Vivadent, Schann, Linchestein Principality). However, no *in vivo* study has evaluated the effectiveness of such procedures during exposure to a curing light.

Thus, the purpose of this *in vivo* study was to measure and evaluate PT changes when intact human premolars were exposed to a high-intensity LED LCU, while either simultaneously applying an air spray from the opposite side of the exposure or not. The research hypotheses were that 1) the application of air spray during LCU exposure will significantly reduce PT rise in comparison to when no air spray is used, and 2) PT values following light exposure with air spray will result in PT values significantly lower than pre-exposure, baseline values.

METHODS AND MATERIALS

Irradiance Measurement of the Polywave LED LCU

The spectral power of the polywave LED light was recorded five times in High mode, using a laboratory grade spectroradiometer (USB 2000, Ocean Optics, Dunedin, FL, USA) and a 6-in integrating sphere (Labsphere, North Sutton, NH, USA), previously calibrated using a National Institute of Standards and Technology (NIST)-traceable light source. The LCU tip end was positioned at the entrance of the integrating sphere, so all light emitted from the unit was captured. Spectral power was measured between 350 and 550 nm, using software (SpectraSuite v2.0.146, Ocean Optics), which also provided a total value within that range. 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 exitance from the curing light.

In Vivo Measurement of Intrapulpal Temperature

The study was previously approved by the local Ethics Committee (protocol #255945). Five patients requiring extraction of first premolars for orthodontic reasons (n=9) were recruited from the orthodontic specialization programs in Ponta Grossa, State University of Ponta Grossa and the Brazilian Association of Dentistry, Parana section. The subjects, four females and one male, ranging from 12 to 30 years old, passed through an initial consultation phase, in which the volunteers were informed about the study aims and all methodology involved in the research. Patient inclusion criteria included 1) treatment plans indicating premolar extractions for orthodontic reasons, 2) the presence of healthy, intact, noncarious, and nonrestored, 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 those patients who were currently under medication. After having the benefits and risks for participating in the study explained, the volunteer subjects, or the subject's legally authorized representative (for subjects under the age of 18 years), signed the informed consent document. The subject's medical history was obtained and reviewed by at least one clinician participating in the study, prior to any treatment being performed.

All teeth tested were anesthetized using a local anesthetic (2% mepivacaine hydrochloride with epinephrine, Mepiadre, DFL Industria e Comercio, Rio de Janeiro, RJ, Brazil). Only intact, upper first premolars were evaluated. The teeth received both infiltrative as well as intraligamental injections. The premolar received isolation with rubber dam. A deep class I preparation was then made on the occlusal surface, using a round diamond bur (#1013, KG Sorensen, Cotia, SP, Brazil), under constant irrigation, until the preparation floor was near the roof of the pulp chamber. The pulp exposure was carefully obtained with the aid of a root canal explorer, so the exposure diameter was as small as possible. After pulp exposure was obtained, a sterile thermocouple probe from a wireless temperature acquisition system (Temperature Data Acquisition-Thermes Wfi, Physitemp, Clifton, NJ, USA) was inserted directly into the pulp chamber. The thermocouple probe was connected to an isolated, battery-driven data acquisition device that wirelessly sent temperature values to a computer, where temperature was displayed and recorded in real time. With the probe remaining in place, the occlusal preparation was then filled using a provisional restorative material (Cavitec, CaiTHEC Ltda, São José dos Pinhais, PR, Brazil), to minimize heat loss from the tooth through the cavity walls and pulp access. The baseline pulpal temperature value was established after approximately 15 to 22 minutes. The emitting end of a high power, polywave LED curing unit (Bluephase 20i, Ivoclar Vivadent), used in its high-power mode (1244 mW/cm^2), was placed directly against the facial enamel surface, in the cervical region. The following exposure conditions were then applied, during which data were recorded at every 0.2 seconds: three seconds prior to light exposure, an air spray from a triple syringe was held 1-mm from the lingual enamel surface, opposite of where the LCU tip was placed (air pressure set to 28 psi). A 30-second exposure in high-intensity mode (radiant exposure of 37.3 J/cm^2) was applied to the facial surface, and the air stream was terminated at the same moment the LCU turned off (30s-H/AIR). A seven-minute time span then passed, to allow baseline pulpal temperatures to return to the pre-exposure values. Another exposure was then given as stated before, but without application of the air spray (30s-H). At the end of temperature acquisition, the probe was carefully removed from the tooth. After testing was completed, the teeth were atraumatically extracted, as planned for the patient's orthodontic treatment. Following extraction, the probe was reinserted into the pulp chamber of some extracted teeth, and X-rays were taken from the proximal surface, with the probe in position as it was intraorally, to verify probe position during testing (Figure 1).

Statistical Analyses

Peak PT during exposure and PT increase during exposure relative to the pre-exposure baseline value (ΔT) were determined. Peak PT data were evaluated using a one-way, repeated-measures analysis of variance, whereas ΔT was compared using a paired Student's *t*-test. All statistical testing was made using a preset α of 0.05. *Post hoc* power analysis was performed for statistical analyses of peak PT and ΔT

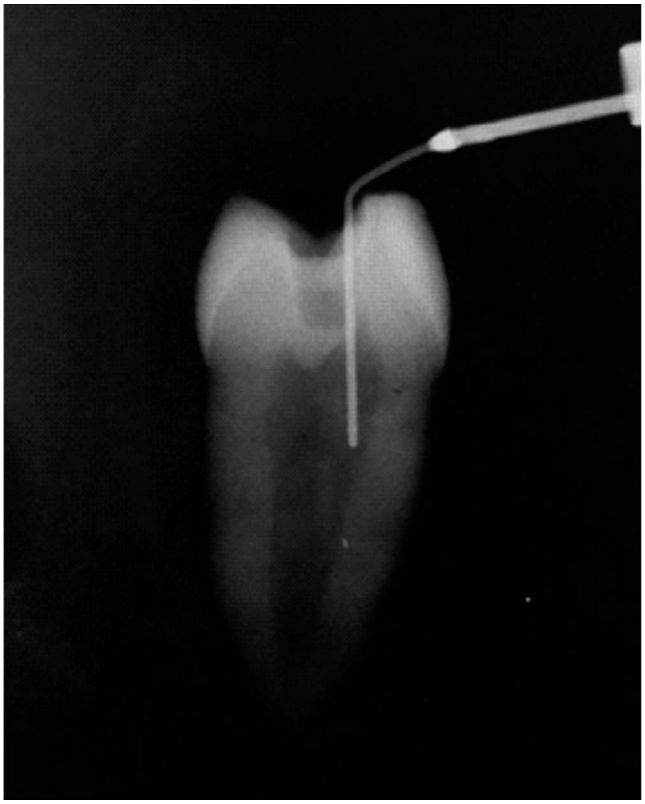

Figure 1. *X-ray analysis after tooth extraction to confirm if the probe was properly positioned into the pulp chamber during data acquisition.*

values. All analyses were performed using commercial statistical software (Statistics 19, SPSS Inc, IBM Company, Armonk, NY, USA).

RESULTS

In Vivo Measurement of Intrapulpal Temperature

For the number of evaluated teeth (n=9), the *in vivo* study was adequately powered for both peak PT and ΔT values (>99.0%; α=0.05). The results of peak PT and ΔT are shown in Table 1. The PT from exposure to the 30s-H condition (37.5±0.5°C) was significantly greater than that of the baseline PT (35.4±0.6°C). On the other hand, the use of the 30s-H/AIR condition resulted in significantly lower PT values (34.0±1.0°C) than the baseline (35.4±0.6°C) (p=0.003). As a result, the ΔT values observed when teeth were exposed to a 30s-H mode were significantly higher (p<0.001) than those observed using the 30s-H/AIR condition.

Table 1: *Means (SD) of Peak Temperature Values (°C) and ΔT (°C) for Each Experimental Condition*[a]

Test Parameter	Baseline	30-sH	30s-H/AIR
Peak temperature	35.4 ± 0.6 B	37.5 ± 0.5 A	34.0 ± 1.0 C
ΔT		2.3 ± 0.5 a	−1.3 ± 0.5 b

[a] *Within a test parameter (row), values identified using similar letters (uppercase: peak temperature; lower case, temperature difference from baseline (ΔT) are not significantly different.*

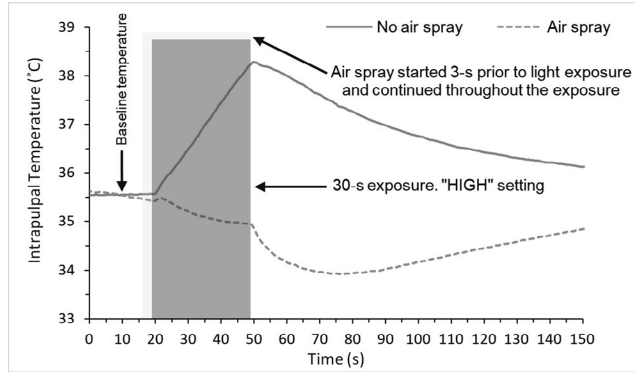

Figure 2. *Representative,* in vivo*, real-time PT profiles during a 30-s exposure on high output mode (30s-H) without (blue line) or with (30s-H/AIR) (orange line) simultaneous application of air spray from the opposite tooth side. Duration of air-spray depicted by the light yellow rectangle, and duration of light exposure represented by the blue box.*

Figure 2 shows representative real-time profiles of PT change during exposure to 30s-H and 30s-H/AIR conditions. Exposure to the 30s-H mode resulted in an immediate PT increase, characterized by an ascending straight line, which was followed by a slow temperature drop, following light termination. On the other hand, exposure to the 30s-H/AIR condition caused a slow PT decrease while the buccal surface was exposed to curing light. When the light terminated and the air spray stopped, PT dropped more quickly, for approximately 30 seconds, before it started to rise again.

DISCUSSION

The data clearly indicate that air spray application during light exposure was able to prevent PT to rise. Therefore, the first research hypothesis was not rejected. These results are in agreement with those from a previous *in vitro* study,[36] which attributed the ability of air flow to remove the hot air around an exposed tooth. According to the authors, the hot air around the exposed tooth would be partly responsible for the temperature increase within the tooth. Moreover, the current results can also be attributed to the thermal behavior of enamel and dentin. In this regard, when an intact tooth is exposed to a curing light, the thermal energy from enamel dissipates inward, toward the dentin and pulp chamber, as well as outward to the ambient environment.[37] Because dentin has a low thermal diffusivity, the thermal energy is not only transferred to the pulp but is also stored within it.[37] This thermal behavior is responsible for gradual dissipation of heat energy toward the pulp, sustaining higher temperature values within the pulp, even after the curing light has shut off, as previously shown.[15] Conversely, when an air flow was started three seconds before the light was turned on and was maintained during light exposure, the temperature of enamel and dentin dropped. Thus, higher thermal energy was required to heat these substrates. Therefore, when air flow and exposure to light occurred simultaneously, the heat generated during the 30-second exposure to the curing light emitting 1244 mW/cm^2 (approximately 37.3 J/cm^2) was not capable of increasing the temperature of enamel and dentin to values that could cause a PT rise. Indeed, based on the real-time analysis of temperature change during a 30-second exposure to light with air flow, a slow PT decrease was noted during exposure to curing light (Figure 2). This finding infers that the use of air flow during exposure to a curing light was more effective in decreasing PT than was light in transferring heat to the pulp. For this reason, it is reasonable to assume that longer exposures to a curing light emitting 1244 mW/cm^2, which is an irradiance value commonly found in commercially available LED LCUs, would not be harmful for the pulp when air flow is applied simultaneously.

Interestingly, the temperature drop in dentin due to air flow not only avoided PT rise during exposure to the LED light but also decreased PT to lower values than that of the baseline PT (Table 1). As a matter of fact, PT values showed a continuing fast decrease for approximately 30 seconds after air flow stopped (Figure 2). Therefore, the second hypothesis was not rejected. This finding confirms the presence of a gradient temperature created between the pulp and the cooled pulp chamber walls, due to the decrease in dentin temperature during air flow. In other words, the lower temperature of dentin chamber walls, in comparison to that of the pulp, causes the heat from the pulp to flow toward the dentin chamber walls by thermal conduction, to reach thermodynamic equilibrium, resulting in the continuous post-air flow PT drop. In a restorative procedure with photo-activated resin-based composites, when sequential tooth exposures to the LED light are required to ensure optimal polymerization of resin composite layers, a prepared tooth having PT lower than the baseline temperature would provide further protection against pulp damage. In that clinical condition, higher radiant exposure values would be required to increase PT to the threshold values considered harmful for the pulp (approximately 42.5°C)[13] than when such restorative procedures are performed on teeth having PT at the baseline values. Further investigation is required to confirm such assumptions.

The current results demonstrate that air flow was very effective in preventing PT rise during exposure to an LED light using its "high" mode in intact premolars *in vivo*. In this context, it is worth noticing that PT rise may be influenced by the translucency and thermal diffusivity of the substrate interposed between the heat source and the pulp.[15,38] Because resin composites may show a wide range in translucency[39] and lower thermal diffusivity depending on the amount and type of filler content,[40] PT rise may be higher during the exposure of a class V preparation to curing light when the prepared cavity is filled with more translucent resin composites having low filler content in comparison to that observed on intact teeth. For instance, previous *in vitro* findings have shown that exposing teeth with a class V preparation either empty or filled with resin composite to a curing light caused higher PT rise than did exposure of an intact tooth to a curing light.[41] As a consequence, one could state that air flow may not be as effective in these clinical scenarios as it was in intact teeth. For this reason, in an attempt to overcome this study limitation, the intact teeth were exposed to LED light for 30 seconds, which is longer than 10- or 20-second exposure usually recommended by the manufacturers of most recently commercially available resin composites. In other words, because of the direct positive relationship between exposure interval and PT rise,[15] the 30-second exposure to light may cause higher PT rise than that expected even when a class V preparation filled with translucent resin composites with high thermal diffusivity is exposed to shorter exposure intervals, such as 10- or 20-second exposure to LED light. For this reason, it is reasonable to assume that applying air flow along with the curing light exposure in these restorative procedures may be as effective as the air flow applied in the condition evaluated in the current study. In addition, because intact teeth were evaluated, similar results could also be expected in procedures involving the delivery of curing light to intact teeth, such as in-office bleaching, when cementing ceramic laminates, or when placing composite resin veneers.[1,42]

Based on these findings, exposure of intact premolars to a curing light along with simultaneous application of an air flow is shown to be an effective method to prevent temperature rise within the pulp during exposure to high irradiance levels. However, because of differences in morphology and dentin thickness among teeth, care should be taken when assuming that similar results should be expected on other teeth, such as anterior incisors. Despite this limitation, such an easy and time-efficient approach should be added to the clinician's routine, because it can reduce the risk of pulp thermal damage when powerful LED devices are used.

CONCLUSION

Within the limitations imposed by this *in vivo* study, it is possible to conclude that 1) air flow applied simultaneously with exposure to LED light is capable of preventing a temperature increase within the pulp during curing light exposure. In addition, 2) this procedure causes a further temperature drop in the pulp after exposure to a curing light.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of approval of the State University of Ponta Grossa. The approval code for this study is #255945.

Conflict of Interest

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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