

Temperature changes in the pulp chamber induced by polymerization of resin-based dental restoratives following simulated direct pulp capping

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Abstract

The objective of this study was to measure temperature changes in the pulp chamber induced by polymerization of resin-based dental restoratives following a simulated procedure of direct pulp capping. Class I cavities with a microperforation at the pulp horn were prepared in extracted human molar teeth. The complete procedure of direct pulp capping and cavity restoration was performed with the root part of extracted teeth fixed in a water bath at 37 °C. Mineral trioxide aggregate, bioactive dentin substitute or calcium-hydroxide paste were used as pulp capping materials. Cavities were restored with a light-cured or chemically-cured resin-modified glass ionomer, universal adhesive and a bulk-fill composite, cured with a high-intensity LED unit. Pulp capping materials caused a slight temperature decrease. Lower temperature increase was recorded during light-curing of the glass ionomer liner after direct capping with mineral trioxide aggregate and calcium-hydroxide than that recorded for the bioactive dentin substitute. Adhesive light-curing increased temperature in all groups with higher mean temperatures in groups with chemically-cured as compared to those for the light-cured glass ionomer liner. Direct pulp capping with mineral trioxide aggregate or calcium-hydroxide followed by the light-cured resin-modified glass ionomer liner and a bonded bulk-fill composite restoration induced temperature changes below the potentially adverse threshold of 42.5 °C.

Keywords: Calcium silicate cement; glass ionomer cement; dental adhesive; resin-based composite; polymer; pulp temperature

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1. INTRODUCTION

Mineral trioxide aggregate (MTA), a calcium silicate cement, is widely accepted in dentistry as an effective direct pulp capping material with the potential to stimulate dentin bridge formation maintaining the level of inflammatory reaction similar to that of Ca-hydroxide [1]. Clinical studies have shown more favorable results of direct pulp capping with MTA than with Ca(OH)₂ pastes [2,3]. MTA and Biodentine, another calcium silicate cement, have shown comparable clinical efficiency in direct pulp capping up to 1 year post-treatment [4].

Although direct pulp capping may be successful as a 2-visit treatment [5], 1-visit treatment seems a more viable approach [2], thereby reducing clinical working time and the risk of infection and iatrogenic trauma to the exposed tissue. Bonded composite restorations are clinicians' first choice due to the wide clinical use of resin-based composites as universal restoratives. Placing a glass ionomer liner over the capping material is recommended to seal it in place and prevent infection [2]. Placement of a bonded composite restoration is inevitably linked with light-curing of adhesive and composite, as well as with a light-cured glass ionomer when used for lining.

Light-curing of restorative materials is associated with temperature increase due to heating of the light-curing unit (LCU) and the exothermic nature of the polymerization reaction [6]. All LCUs have been shown to exert a thermal

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challenge on the pulp [7]. LCUs also increase intrapulpal temperature during bleaching procedures, albeit to a smaller effect due to the insulating capability of enamel and dentin [8].

It is still unclear how much heat a vital pulp can sustain and in what period of time before irreversible changes occur. A threshold of 5.5 °C [9] is quoted in virtually all studies on this subject. Another study reported that the temperature increase up to 14.7 °C, with temperatures exceeding 43 °C for 80 and 180 s, which may be considered clinically relevant periods, did not cause irreversible changes in human pulp tissue [10].

In vitro studies of the temperature rise in the pulp chamber during restorative procedures pointed to the contributing factors such as the remaining dentin thickness [11-13], type of the restorative material [11,13-17], type of LCU [16,18,19], curing times [19,20] and distances [21]. It was also reported that an experimental setup involving simulated microcirculation in the pulp chamber resulted in a lower temperature rise [12,15]. Only a few studies reported on temperature changes in the pulp chamber in relation to pulp capping materials, placed as an “indirect cap” in permanent [21,22] or “direct cap” in primary teeth [23].

The aim of this study was to measure temperature changes in the pulp chamber during a complete simulated direct pulp capping procedure including placement of a pulp capping material, lining with a glass ionomer and restoring with a bonded bulk-fill composite restoration. Null hypotheses were: (1) there are no statistically significant differences in temperature changes between pulp capping materials covered with a GIC liner, (2) there are no statistically significant differences in temperature changes between a light-cured and chemically-cured glass ionomer liners, (3) there are no statistically significant differences in temperature changes between groups when curing the adhesive and (4) there are no statistically significant differences in temperature changes between groups when curing the bulk-fill composite.

2. MATERIALS AND METHODS

Sixty-five human, intact molars extracted for orthodontic or periodontal reasons were used in the study following the approval by the University of Belgrade School of Dental Medicine Ethics Committee (No. 36/2 of April 10, 2018). The roots of each tooth were embedded in super hard gypsum 2 mm below the enamel-cementum junction. The cusps were cut off at the bottom of the central fissure creating a flat surface. A round diamond bur in a water-cooled handpiece was used to prepare standardized class I cavities 4x4 mm. A new bur was used after 5 teeth. The roots were cut off 2 mm below the enamel-cementum junction with inter-radicular dentin removed using a round carbide bur to expose the pulp chamber. A microperforation (\varnothing 0.5 mm) was prepared using a round carbide bur at the most prominent pulp horn.

The experimental design schematic is presented in Figure 1. A K-type thermocouple (Measurement Computing, Norton, MA, USA) was placed in the pulp chamber in contact with the microperforation and the surrounding dentin. The pulp chamber was sealed with A-type silicone impression material (Elite HD+, Zhermack SpA, Badia Polesine, Italy) to prevent water access into the prepared cavity. Upon silicone setting, the specimens were placed in a water bath set at 37°C. Temperature was measured during the entire experiment at 1 s scans using the said K-type thermocouple attached to a data-logger and a PC equipped with TracerDaq software (Measurement Computing, Norton, MA, USA).

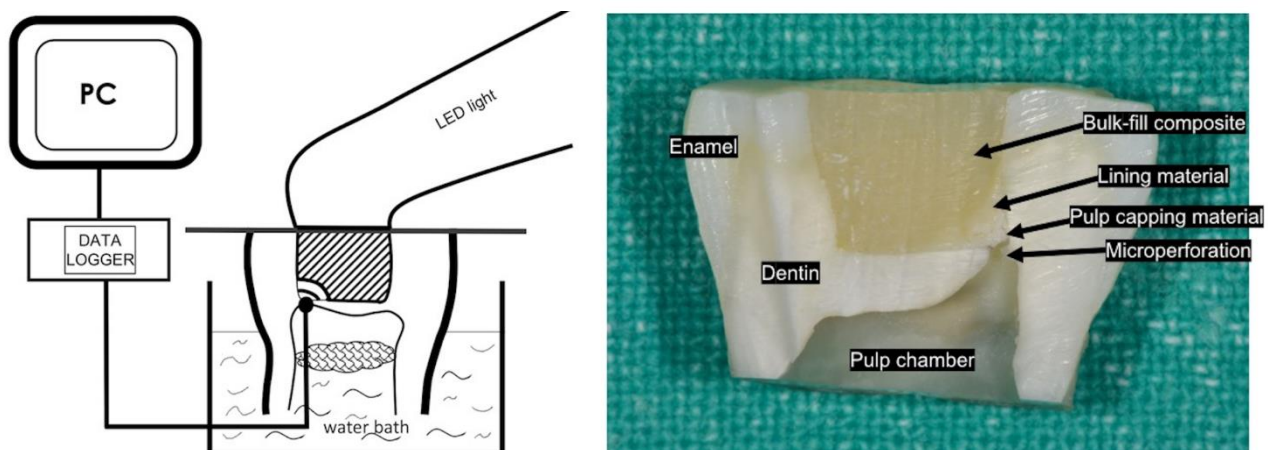


Fig. 1. Schematic presentation of the experimental setup and a photograph of a representative specimen sectioned parallel to the long axis of the tooth.

Table 1 presents details of the materials used in the study. All materials were used according to instructions for use provided by the respective manufacturer. The prepared specimens were allocated to eight groups (N=5/group):

Group 1: MTA + Vitrebond nonLC + SBU + Filtek Bulk

Group 2: Biodentine + Vitrebond nonLC + SBU + Filtek Bulk

Group 3: Calxyd + Vitrebond nonLC + SBU + Filtek Bulk

Group 4: MTA + Vitrebond LC + SBU + Filtek Bulk

Group 5: Biodentine + Vitrebond LC + SBU + Filtek Bulk

Group 6: Calxyd + Vitrebond LC + SBU + Filtek Bulk

Group 7 (control): Vitrebond LC + SBU + Filtek Bulk

Group 8 (control): Vitrebond nonLC + SBU + Filtek Bulk

Table 1. Materials used in the study

Material (Code)	Manufacturer	Type	Composition
Master-Dent MTA (MTA)	Dentonics, Monroe, NC, USA	Pulp capping material	Powder: Tricalcium silicate, dicalcium silicate Liquid: undisclosed
Biodentine (Biodentine)	Septodont, Saint- Maur-des-Fossés, France	Pulp capping material	Powder: Tricalcium silicate, dicalcium silicate, calcium carbonate, zirconium oxide, iron oxide. Liquid: Calcium chloride, hydrosoluble polymer, water
Calxyd (Calxyd)	Spofa Dental, Jicin, Czech Republic	Pulp capping material	Calcium hydroxide, glycerin, water
Vitrebond (Vitrebond)	3M ESPE, St. Paul, MN, USA	Lining material	Powder: Fluoroalumino-silicate glass. Liquid: 2-hydroxyethyl methacrylate, water, initiators
Single Bond Universal (SBU)	3M ESPE, St. Paul, MN, USA	Universal adhesive	2-hydroxyethyl methacrylate, Bisphenol A diglycidyl ether dimethacrylate, decamethylene dimethacrylate, ethanol, silane treated silica, water, 2-propenoic acid, 2-methyl-, reaction products with 1,10- decanediol and phosphorous oxide (P2O5), copolymer of acrylic and itaconic acid, (dimethylamino)ethyl methacrylate, camphorquinone, dimethylaminobenzoat(-4), 2,6-di-tert-butyl-p-cresol
Filtek Bulk Fill Posterior (Filtek Bulk)	3M ESPE, St. Paul, MN, USA	Bulk-fill composite (sculptable)	Silane treated ceramic, silica and zirconia, aromatic urethane dimethacrylate, YbF3, diurethane dimethacrylate, 1,12-dodecane dimethacrylate, water, Pentanedioic acid, 2,2-dimethyl-4-methylene-, reaction products with glycidyl methacrylate, ethyl 4-dimethyl aminobenzoate, benzotriazole, TiO ₂

The pulp capping material was applied to the perforation in a portion approx. 1 mm in diameter using a dental probe. The material was gently pressed by a small cotton pellet to cover the microperforation and lightly touch the surrounding dentin.

The resin-modified glass ionomer liner (Vitrebond) was applied to cover the pulp capping material and up to 1 mm around it using a dental probe. It was either light-cured for 20 s using a high-intensity light-curing unit Elipar DeepCure (3M ESPE, St. Paul, MN, USA) (group denoted as Vitrebond LC) or left to be chemically-cured over a period of 2 min 30 s (group denoted as Vitrebond nonLC).

The Single Bond Universal adhesive was applied using a disposable applicator following a self-etch mode on dentin and light-cured for 10 s using the same light-curing unit by placing the light tip in contact with the occlusal surface.

The bulk-fill composite was injected in the cavity, lightly adapted using a round condenser, covered with a Mylar strip and light-cured for 20 s with the light tip in contact with the Mylar strip. Another 20 s light-curing was performed 5 s after the first was completed.

In control groups only Vitrebond liner was placed directly to cover the microperforation and up to 1 mm of the surrounding dentin. It was either light-cured or chemically-cured before placing the adhesive and composite as previously explained.

Temperature data were analyzed using methods of descriptive and analytical statistics, namely box-and-whisker plots and one-way analysis of variance (ANOVA) with Tukey's post hoc test at the level of significant set at 0.05. Statistical analysis was performed using Minitab Express (Minitab Inc., State College, PA, USA).

Furthermore, temperature data were used to calculate heat absorption by the tooth in each stage of the simulated pulp capping procedure, using the following equation:

$$Q = Cm\Delta T \quad (1)$$

where Q is the heat, C is the specific heat capacity, m is the mass of the tooth specimen and ΔT is the change in temperature. The specific heat capacity of the tooth tissue was determined to be $0.30 \text{ cal / g } ^\circ\text{C}$ ($1.255 \text{ J / g } ^\circ\text{C}$) [24].

3. RESULTS

Temperature at the light tip of the light-curing unit was $53.61 \pm 0.93 \text{ } ^\circ\text{C}$ for 10 s and $58.97 \pm 0.93 \text{ } ^\circ\text{C}$ for 20 s exposure. The mean temperature values in the empty cavity were in the range of $47.49\text{--}49.65 \text{ } ^\circ\text{C}$ and were not significantly influenced by the presence of the Mylar strip, the 2 mm distance of the light tip or increased exposure time ($p = 0.2063$). The remaining dentin thickness at the cavity floor was $1.29 \pm 0.23 \text{ mm}$.

Figure 2 presents real-time temperature measurements during simulated direct pulp capping procedures. Two peaks during composite light-curing, associated with two 20 s light exposures and a 5 s gap, show only a slight decrease followed by the increase in temperature during the second light exposure exceeding the first temperature peak.

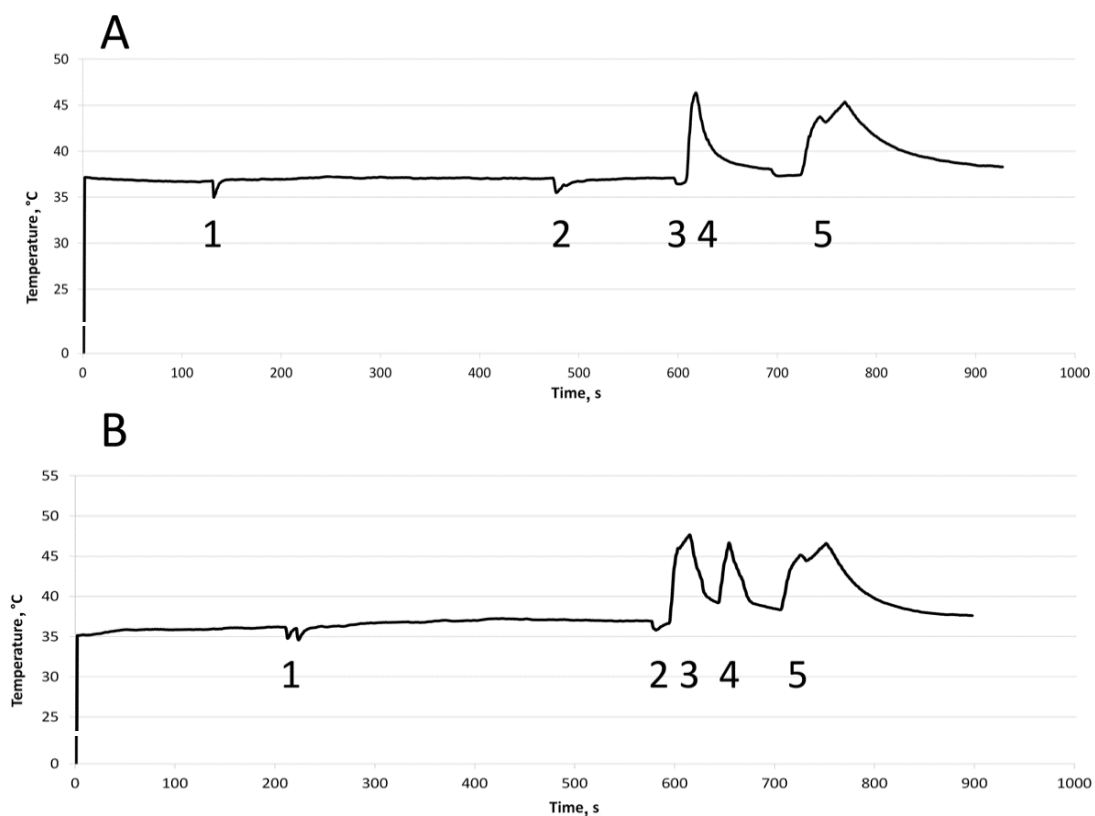


Fig. 2. A representative image of real-time temperature changes during placement of pulp capping materials and cavity restoration with resin-based dental restorative materials. (A) Biodentine_Vitrebond nonLC group: 1 - Biodentine placement, 2 - Vitrebond placement, 3 - adhesive placement, 4 - adhesive light-curing and 5 - composite light-curing. (B) Biodentine_Vitrebond LC group: 1 - Biodentine placement, 2 - Vitrebond placement, 3 - Vitrebond light-curing, 4 - adhesive light-curing and 5 - composite light-curing. Note either one or two dropping peaks during Biodentine placement indicating differences in material adaptation at the microperforation site with the cotton pellet.

Placement of pulp capping materials caused a slight drop in temperature (Biodentine $35.49 \pm 0.39 \text{ } ^\circ\text{C}$; MTA $35.48 \pm 0.22 \text{ } ^\circ\text{C}$ and Calxyd $34.10 \pm 1.36 \text{ } ^\circ\text{C}$) with no statistically significant differences between the groups ($p = 0.0660$). Exposure of different pulp capping materials to the high intensity light-curing unit increased temperature from the baseline to $43.95\text{--}46.62 \text{ } ^\circ\text{C}$ in the order Calxyd < MTA < Biodentine ($p = 0.0913$) (Fig. 3).

Light-curing Vitrebond liner over the pulp capping material caused a significantly higher temperature as compared to all chemically-cured Vitrebond groups ($p < 0.05$), which did not induce temperature changes. Lower temperatures

were registered in the Calxyd_Vitrebond LC and MTA_Vitrebond LC groups than in the Biodentine_Vitrebond LC and control groups ($p < 0.05$). (Fig. 4).

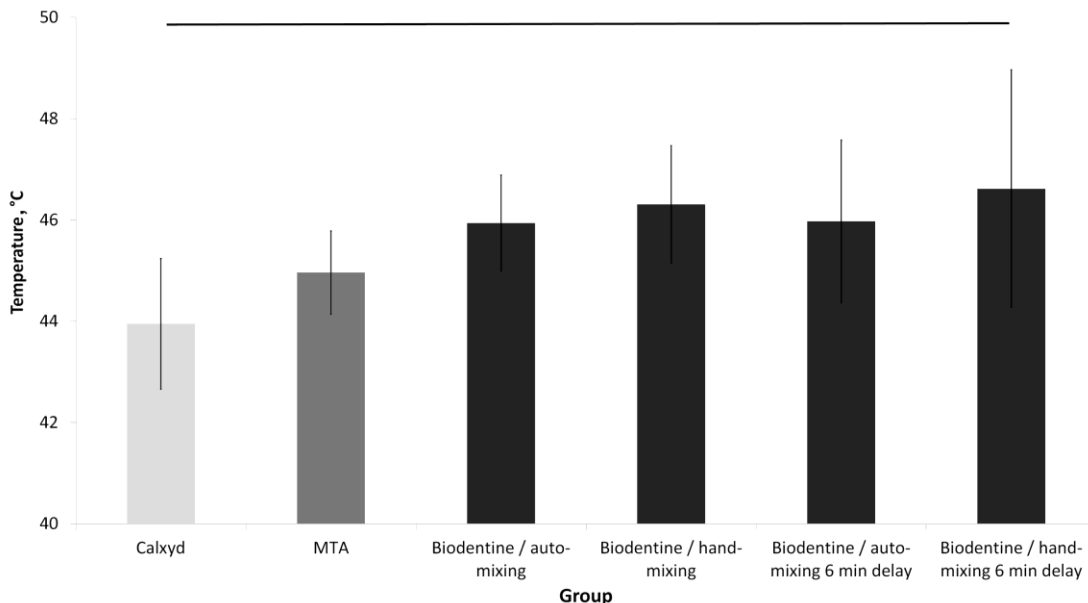


Fig. 3. Temperature at the microperforation site during exposure of different pulp capping materials to the high intensity light-curing unit for 20 s. The horizontal line indicates no statistically significant difference between groups ($p > 0.05$)

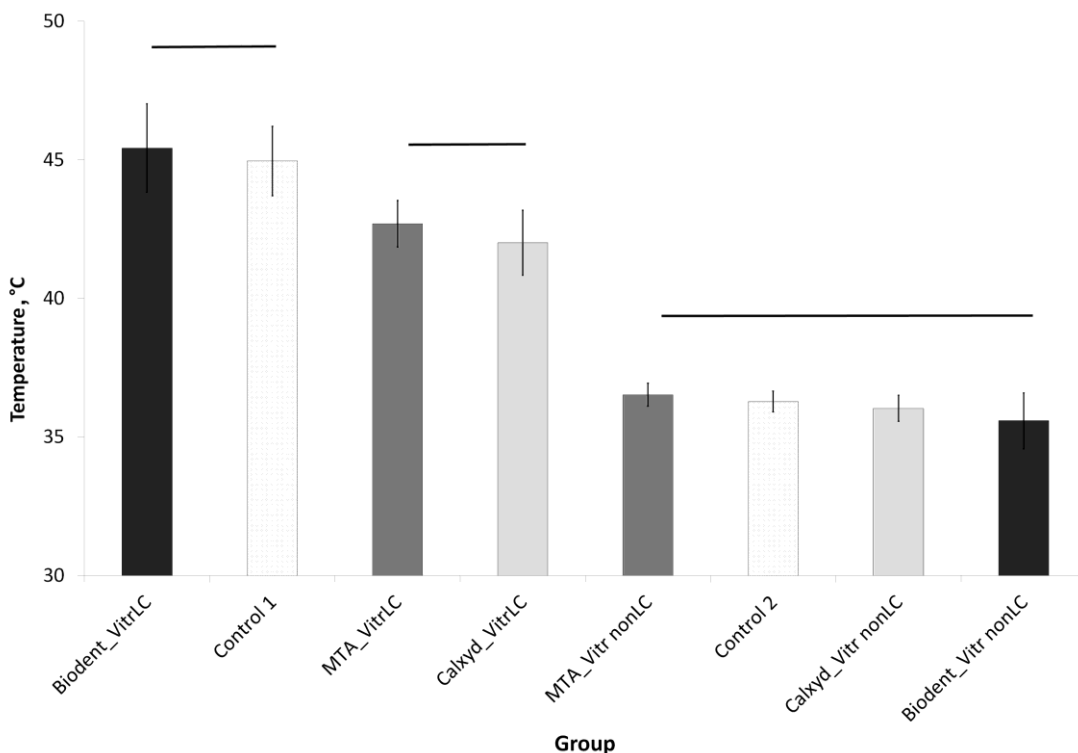


Fig. 4. Temperature at the microperforation site during light- and chemical-curing of the Vitrebond liner. Groups connected with horizontal lines are not significantly different ($p > 0.05$)

Light-curing adhesive in groups Calxyd_Vitrebond LC and MTA_Vitrebond LC resulted in lower temperatures than that in the Biodentine_Vitrebond non-LC group ($p < 0.05$) and were comparable to those in the MTA_Vitrebond non-LC and Biodentine_Vitrebond LC groups ($p > 0.05$). Corresponding groups with the same pulp capping material and a different liner curing mode showed similar temperatures during the adhesive light-curing e.g. the Calxyd_Vitrebond LC vs. Calxyd_Vitrebond non-LC ($p > 0.05$) albeit the mean temperatures were slightly higher in all non-LC than in LC groups (Fig. 5).



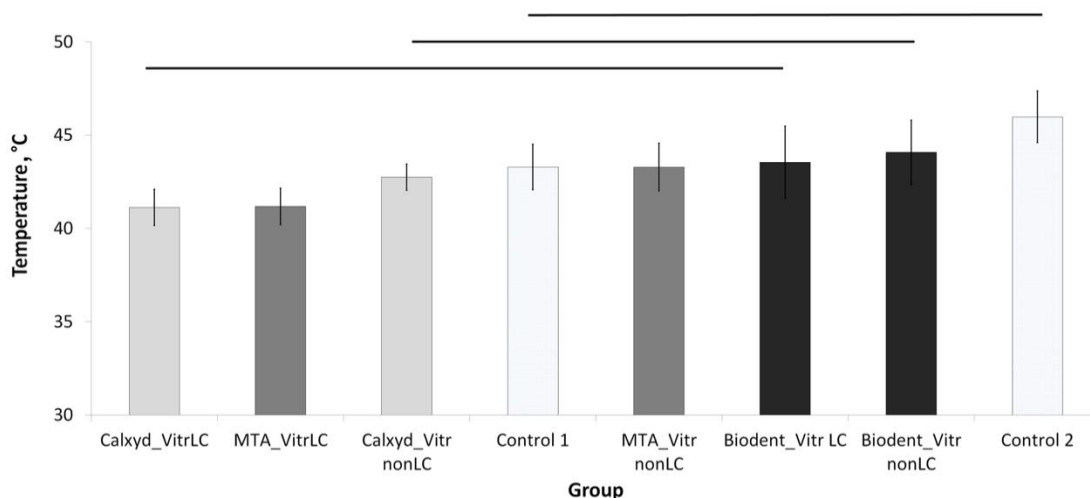


Fig. 5. Temperature at the microperforation site during light-curing of the Single Bond Universal adhesive. Groups connected with horizontal lines are not significantly different ($p > 0.05$)

Statistically significant differences were not found between tested groups during the composite light-curing ($p > 0.05$). Mean temperatures were in the range of 40.77-42.26 °C (the first light-curing for 20 s) and 41.78-43.14 °C (the second light exposure after a 5 s gap).

Heat absorbed by the tooth tissue during different stages of the simulated pulp capping procedure was calculated by the Eq. (1) and presented in Table 2.

Table 2. Heat absorbed by the tooth tissue

	Empty cavity	Liner light-curing direct (control)	Liner light-curing over the pulp cap	Adhesive light-curing	Composite light-curing
	Absorbed heat, J				
Mean	20.0	14.9	11.0	10.4	8.1
SD	4.4	2.6	2.7	2.9	2.2

4. DISCUSSION

The first null hypothesis was rejected as significant differences were found between the Biodentine and MTA or Ca(OH)₂ pulp capping materials when covered with a light-cured glass ionomer liner. The second null hypothesis was rejected as significant differences were found between the two Vitrebond liner groups that is with chemical- and with light-curing. The third null hypothesis was rejected as significant differences during the adhesive light-curing were detected between the Biodentine_Vitrebond nonLC and Calxyd or MTA_Vitrebond LC groups. The fourth null hypothesis was upheld as differences in temperature changes were not statistically significantly different during light-curing of the bulk-fill composite restoration over various pulp capping materials.

Water circulation was previously introduced in the experimental design in an attempt to simulate pulpal microcirculation and its cooling effect [12,13,15]. However, it is not determined to what extent the experimental water circulation is clinically relevant in mimicking the actual pulpal microcirculation effects on heat dissipation. Excluding water circulation in the present study could be considered as the ‘worst case’ scenario as cooling was entirely absent. It was necessary to prevent water access into the prepared cavity since it would obstruct curing of resin-based materials.

Class I cavities in the present study allowed a more clinically relevant heat transfer by the surrounding enamel and dentin instead of disk-shaped specimens used in previous studies [16,17,21]. A thermocouple placed at the microperforation site in contact with the capping material and surrounding dentin corresponds to the position of the pulpal wound in a clinical situation with the perforated pulp. Temperature measured by the thermocouple in this *in vitro* setup relates to the temperature to which the pulpal tissue would be exposed during a direct pulp capping procedure.

Pulp capping materials showed some insulating capability as 3-5 °C temperature drop was recorded with pulp capping materials in place as compared to the direct exposure of the microperforation site to the light-curing unit. This insulating ability of the pulp capping materials was further confirmed in heat absorption calculations, as nearly 30 % lower heat was absorbed during liner light-curing with pulp capping materials in place as compared to the control group without the pulp capping material.

Despite the manufacturer's recommendation to automatically mix Biodentine, some clinicians could opt for hand-mixing in order to save material, hence a hand-mixed group was included in the study. The results showed no statistically significant differences in temperature changes irrelevant of the Biodentine manipulation. From the standpoint of the intrapulpal temperature, it may be recommended that Biodentine, either hand- or auto-mixed is covered with a liner immediately after the placement, without the 6-min delay for material setting.

Significantly higher temperatures in the Biodentine_Vitrebond than in the MTA or Calxyd_Vitrebond groups could be associated with the exothermic setting reaction of Biodentine [25]. The MTA material used in the present study (Master-Dent MTA) contains gel instead of distilled water, so that the hydration reaction of calcium oxide leading to formation of $\text{Ca}(\text{OH})_2$ as observed in the MTA Angelus [25] may be retarded in the MTA used leading to a lower temperature in the initial phase. Despite the fact that temperature exceeded the potentially detrimental threshold of 42.5 °C in the Biodentine_Vitrebond LC group, this elevated temperature lasted only 15-30 s before dropping to below 40 °C. The clinical relevance of this 15-30 s period of temperature exceeding the 42.5 °C threshold in the Biodentine group is likely non-existent, having in mind the results reported by Baldissara *et al.* [10] who reported that intrapulpal temperature exceeding 43°C for 80 to 180 s did not cause irreversible changes in human pulp tissue.

Temperature changes ranging between 1.8 and 9.5 °C during light-curing of various lining materials (light-cured resin-based calcium-hydroxyde, calcium-silicate, calcium-hydroxyphosphate and glass ionomer cements) were previously reported for specimens with 1 mm of the remaining dentin thickness [21,22,26]. Our results showed that the chemically-cured lining material does not increase the temperature in the pulp chamber when it is placed over a direct pulp capping material. Temperature changes during liner light-curing elevated the pulp chamber temperature in the range of 5 - 8.5 °C, which was comparable to temperature changes during light-curing of lining materials in previous studies [21,22,26]. This finding indicates that about 0.5 mm pulp exposure closed with any of the clinically recommended pulp capping materials sustains a comparable thermal challenge to the pulp as a liner-protected deep cavity without the pulp exposure.

Somewhat unexpected was the result that the curing adhesive over the Vitrebond liner showed a tendency for higher temperatures in the Vitrebond nonLC group than in the Vitrebond LC group. For the same pulp capping material, use of the Vitrebond nonLC resulted in higher temperatures than that recorded for the Vitrebond LC during the adhesive curing phase. This finding could be related to the incomplete curing reaction of this resin-modified glass ionomer cement during the manufacturer's claimed chemical-curing period of 2.5 min. It was previously shown that chemical-curing without the additional light-curing of a resin-modified glass ionomer resulted in a significantly lower degree of conversion compared to that achieved by light-curing [27]. Exposure of the chemically-cured Vitrebond nonLC to light during the subsequent adhesive curing could facilitate additional polymerization of the uncured methacrylate groups in this material. This exothermic reaction could have contributed to slightly higher temperatures in the Vitrebond nonLC group as compared to the Vitrebond LC group during adhesive curing. The present results suggest that placing a light-cured liner over a pulp capping material may be recommended for a more predictable and sustainable heat challenge to the underlying pulp tissue.

Light-curing of the bulk-filled composite did not induce significant differences in temperature changes relative to pulp capping materials or liner curing modes. All temperatures were below the 42.5 °C threshold during the first light-curing of 20 s. In some groups, the additional 20 s light exposure caused temperatures to exceed this threshold. Research has shown that extended curing time of sculptable bulk-fill composites [28] may be required for better conversion and that manufacturer's curing times should serve as a minimum curing time [16]. Groups with MTA and $\text{Ca}(\text{OH})_2$ pulp capping materials presented temperature increases below the 42.5°C threshold during the second light exposure of the bulk-fill composite restoration.

The obtained results for temperature changes associated with light-curing of the Filtek Bulk Fill Posterior are in accordance with previous studies reporting on other bulk-fill composites and cavity designs [29-31]. Bulk-fill composites, when tested in a water bath at 36-37 °C showed temperature increases in the pulp chamber ranging from 2.8 °C in primary [29] to 5 °C in permanent molars [31]. A flowable bulk-fill composite in deep cavities with the 0.5 mm remaining dentin thickness without a liner resulted in temperature changes up to 40 °C at the pulp dentin even though the material itself showed temperatures exceeding 50 °C at the bottom of the restoration [30]. These findings suggest that the remaining dentin thickness and direct pulp capping and lining materials exhibit sufficient insulating potentials to minimize effects of the exothermic reaction of bulk-fill composites with different resin contents coupled with the radiant heat of the light-curing unit.

Heat absorption calculation shows the amount of heat the specimen receives in different capping phases. The highest heat amount was absorbed when an empty cavity was irradiated with the light-curing unit. As would be expected, direct exposure of thermocouples at the microperforation site led to the highest temperature rise. As lining and restorative materials are placed and light-cured, the absorbed heat decreased, thereby reducing the risk of a thermal injury to the pulp tissue.

5. CONCLUSION

Direct pulp capping with an MTA or Ca-hydroxide-based material followed by a light-cured resin-modified glass ionomer liner and a bonded bulk-fill composite restoration resulted in temperature changes at the microperforation site below the potentially adverse threshold of 42.5°C. Biodentine was associated with higher temperature increases during various stages of the procedure. Placement of a chemically-cured glass ionomer lining material did not induce temperature changes during its curing reaction. However, the material may not be fully cured during the manufacturer's recommended time resulting in an additional temperature rise during adhesive light-curing.

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SAŽETAK**Promene temperature u komori pulpe indukovane polimerizacijom dentalnih restaurativnih materijala na bazi smole nakon simuliranog direktnog prekrivanja pulpe**

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(Naučni rad)

Cilj ovog rada je bio da se izmere temperaturne promene u komori pulpe indukovane polimerizacijom dentalnih restaurativnih materijala na bazi smole nakon simulirane procedure direktnog prekrivanja pulpe. Kaviteti I klase sa mikroperforacijom u predelu roga pulpe preparisani su na ekstrahovanim humanim molarima. Kompletan postupak direktnog prekrivanja i restauracije kaviteta urađen je nakon fiksacije korenskog dela zuba u vodenom kupatilu na temperaturi od 37 °C. Mineralni trioksidni agregat, bioaktivni dentinski zamenik ili pasta na bazi Ca(OH)₂ korišćeni su kao materijali za direktno prekrivanje pulpe. Kaviteti su restaurirani svetlosno-polimerizujućim ili hemijski-polimerizujućim smolom-modifikovanim glas jonomer cementom, univerzalnim adhezivom i "bulk-fill" kompozitom, polimerizovanim LED lampom velikog intenziteta. Materijali za direktno prekrivanje pulpe doveli su do minimalnog pada temperature. Manji porast temperature zabeležen je tokom svetlosne polimerizacije glas jonomer lajnera nakon direktnog prekrivanja mineralnim trioksidnim agregatom i Ca(OH)₂ nego bioaktivnim dentinskim zamenikom. Polimerizacija adheziva uzrokovala je porast temperature u svim grupama i to sa većim srednjim vrednostima temperature u grupama sa hemijski- polimerizujućim glas jonomer lajnerom nego u grupama sa svetlosno-polimerizujućim glas jonomer lajnerom. Direktno prekrivanje pulpe mineralnim trioksidnim agregatom ili Ca(OH)₂ praćeno svetlosnom polimerizacijom smolom-modifikovanog glas jonomer lajnera i adhezivnom restauracijom "bulk-fill" kompozitom uzrokuje temperaturne promene ispod potencijalno štetnog praga od 42,5 °C.

Ključne reči: kalcijum silikatni cement; glas jonomer cement; dentalni adheziv; kompozit na bazi smole; polimer; temperatura pulpe