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ORIGINAL ARTICLE

The Effect of Restoration Polymerization and Residual Dentine Thickness on Thermal Changes of Pulp Chamber of Immature Permanent Teeth

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ABSTRACT
Objective: To evaluate the pulpal temperature changes due to the polymerisation of resin and glass ionomer-based materials in dentine thicknesses in immature permanent teeth with open apices. **Material and Methods:** Forty extracted sound human third molar teeth with open apices were included. The width of the cavities prepared on the occlusal surface was 4×5 mm. The depth was 2 mm in the resin groups. 4 mm in the groups in which glass ionomer liner was applied before composite restoration. The coronal parts of the samples were then placed on an acrylic plate with three gaps for feeding-extraction needles and the thermocouple. The temperature changes were recorded. The data was analyzed by SPSS. Statistical significance was accepted as $p<0.05$. **Results:** The temperature increase in the group of 1 mm remaining dentin thickness revealed higher results than the values detected from the 2 mm group (1.01 °C) (p=0.00). The mean values (1.49 °C, 1mm) of temperature changes in only glass ionomer applied group were lower than the avarage values (2.210°C, 1mm) determined in the polymerization process of resin composites with light-emitting diode devices. **Conclusion:** In a remaining dentin thickness of 1 mm in teeth with open apices, using a glass ionomer liner might be a useful effort for protecting the pulp from the heat generated by polymerisation devices.

Keywords: Composite Resins; Glass Ionomer Cements; Tooth Apex; Dental Pulp Test.

Introduction

The developmental stage of the tooth may cause different anatomical and physiological variations, and differences may be detected in the anatomical structure and physiological features in a tooth with open apices in comparison to a mature tooth with completed apical development. Accordingly, the age and developmental stages of the teeth may affect the dentine permeability for thermal, mechanical, and microbial stimuli. The wider dentine tubules and increased permeability are the main reasons for the rapid progression of dental caries in young and immature teeth, and their high conductivity capacity is also prevalent in thermal stimuli [1-4].

The temperature of pulp tissue may be affected by various factors. The instrumentation during cavity preparation, the polymerization process of resin materials, bleaching procedures, and the exothermic reaction of dental materials may lead to pulpal temperature changes in reversible or irreversible ways [2,5]. Previously, Zach and Cohen [6] detected that the critical degree that may lead to pulpal damage was 5.5 °C. Considering the fact that the physiological intrapulpal temperature is known to differ between 34 and 35°C [7], it can be concluded that the increases in intrapulpal temperature exceeding 42 to 42.5°C may lead to irreversible damage [7-9] and this phenomenon might have irreversible effects on the pulp's health and viability.

Various studies have been conducted assessing the parameters affecting the changes in pulp temperatures [10-12]. In the literature review, no study was available assessing the pulpal temperature changes in immature teeth relevant to different remaining dentine thicknesses and whether the use of a glass ionomer liner or not. Considering the aforementioned data, the present study aimed to assess the pulpal temperature changes due to the polymerization of resin composite and glass ionomer materials in a dentine thickness of 1 mm and 2 mm in immature permanent teeth. The hypotheses of the present study were as follows: 1) A correlation could be detected regarding the thickness of remaining dentin and the thermal changes in the pulp chamber of immature teeth with open apices, and 2) Utilizing the use of an additional liner might have a favorable effect on the pulp temperature changes.

Material and Methods

Ethical Approval

The research protocol was conducted in line with the principles of the Helsinki Declaration, including all revisions, and with the approval of the Kayseri Erciyes University Ethical Committee (2022-357, 05/11/2022). Access to data was restricted to the researchers, and informed consent was obtained from the legal representatives of all participants before tooth extraction.

Sample Size Calculation and Experimental Groups

The sample size was calculated by G*Power Software based on an effect size of 0.5, an alpha significance level of 0.05, and a beta of 0.20 to achieve a power of 80%. Accordingly, for each group, ten samples were required. Although six groups were determined, the applications of groups 3-5 and 4-6 were performed on the same tooth samples. Thus, a total of 40 samples of sound-impacted wisdom teeth that were decided to be extracted due to surgical reasons were included in this study. Forty extracted sound immature molar teeth with open apices were used. The selection criteria for the samples were based on ICDAS (International Caries Detection and Assessment System) scores [13]. Accordingly, samples meeting the ICDAS score of 0 (sound tooth surface) were included in the study procedures. In this context, caries-free immature third molars with open apices were included and cleaned using a periodontal scaler under tap water. The samples remained in 0.1% thymol solution until the experiment date for one month.

Cavity Preparation

The enamel of the occlusal part of the samples was abraded, and roots were removed under water cooling using a carbon disk bur from 2 mm apical of the cementoenamel junction. The pulp residues were removed with hand tools, and the pulp chamber was irrigated with 5.25% sodium hypochlorite and distilled water. Cavities were prepared using a diamond fissure bur (no: 015, Romi Diamond, Israel). The width of the cavities was 4×5 mm, and the depth was 2 mm in resin-applied groups and 4 mm in the groups in which glass ionomer liner was applied before the composite restoration. The remaining dentin thickness was standardized to 2 and 1 mm between the cavity base and the pulp ceiling, and the accuracy of this thickness was confirmed by an orthodontic caliper (Iwanson, Pearson). The width of the cavity borders was standardized by affixing 4×5 mm labels to the occlusal surface, and the outside surface of the label was painted with nail polish. The cavity preparation was finished by the polished area. The study groups are listed in Table 1.

Table 1. Description of the experimental groups and the materials used in the study.

Groups	Remaining Dentin Thickness	Materials	Brand Name and Manufacturer
G 1	1 mm	Composite Resin	G-ænial™ A'CHORD, GC Europe
G 2	2 mm	Composite Resin	G-ænial™ A'CHORD, GC Europe
G 3	1 mm	Glass Ionomer Liner	Imıcryl, Nova Glass, Konya,Türkiye
G 4	2 mm	Glass Ionomer Liner	Imıcryl, Nova Glass, Konya,Türkiye
G 5	1 mm	Composite after Glass Ionomer Application	G-ænial™ A'CHORD, GC Europe and Imıcryl, Nova Glass, Konya,Türkiye
G 6	2 mm	Composite after Glass Ionomer Application	G-ænial™ A'CHORD, GC Europe and Imıcryl, Nova Glass, Konya,Türkiye

Pulpal Microcirculation Model

Considering the fact that measuring the intrapulpal temperature in human subjects is both unethical and unfeasible, previous studies have utilized *in-vitro* simulation models to assess the intrapulpal temperature changes. Savas et al. [12] designed a pulpal micro-circulation model, and this simulation was preferred for use in the current study. Pulpal microcirculation was achieved by using deionized water with an infusion set. Teeth were placed and fixed with a light-curing adhesive cement (Panavia, Kuraray) on an acrylic plate, and 3 gaps were performed on it. Two of them were for the feeding and the extraction needles of deionized water at room temperature. The thermocouple was placed into the third gap to assess the pulp chamber's temperature changes. The J-type thermocouple (Schneider) was placed into a thermal paste (Rampage TM130), which was applied on the upper surface of the pulp chamber In this design, while deionized water was led into the pulp in one way, the excess water was drained by another similar to *in-vivo* conditions. The flow rate of water was determined as 1 ml/sec., and intra-pulpal pressure was adjusted to 15 cm H_2O in accordance with the previous studies [10,14]. The study design was schematized in Figure 1.

Procedures Followed in the Experimentations

In Group 1 and Group 2, standardized occlusal cavities in a width of 4×5 mm and in a depth of 2 mm were prepared. The remaining dentine thickness of 1 mm (Group 1) and 2 mm (Group 2) through the pulp ceiling was achieved by measuring with a caliper. The sample was placed on the acrylic plate and fixed. The pulpal microcirculation model described above was achieved. The initial temperature was detected, and the composite resin of 2 mm thickness was placed on the cavity. The temperature changes were recorded in real-time by the time the composite placement was started, and according to the manufacturer's instructions, the polymerizatıon for 20 seconds was completed with COXO type Penguin (Foshan COXO Medical Instrument Co., Ltd, China).

The difference between the temperature (ΔT) at the time polymerization completed (T_2) and the initial degrees (T_1) was calculated in accordance with the formula [10]: $\Delta T = T_2 - T_1$

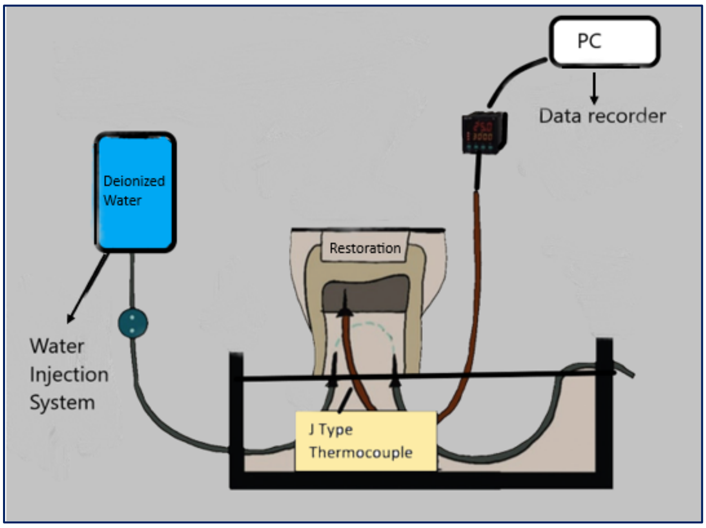

Figure 1. Schematized design of the study.

In Groups 3 and 4, standardized occlusal cavities in a width of 4×5 mm and in a depth of 4 mm (The eligible depth of the cavity for the application of 2 mm glass ionomer liner and 2 mm composite resin) were prepared. The remaining dentine thickness of 1 mm (Group 3) and 2 mm (Group 4) through the pulp ceiling was achieved by measuring with a caliper. The pulpal microcirculation model described above was achieved. The initial temperature was detected and glass ionomer cement at a depth of 2 mm was placed on the cavity. The temperature changes were recorded in real-time by the time the glass ionomer cement placement was started, and the polymerization was completed. The values of the increase in the temperature were detected as the end of the exothermic polymerization reaction of glass ionomer cement. The difference between the temperature at the time polymerization was completed and the initial degrees was calculated.

In Group 5, following the polymerization of glass ionomer liner application in the 1 mm dentine thickness group (Group 3), the needed time until the temperature in the pulp chamber was stabilized was achieved. When the temperature was near the initial room temperature degrees (22 °C), the placement of composite resin was started, and the temperature changes were recorded in real-time by J type thermocouple. The difference between the initial and the last temperature recorded in the pulp chamber was calculated. These experiments were performed on the same samples as Group 3.

In Group 6, following the polymerization of glass ionomer liner application in the 2 mm dentine thickness group (Group 4), the needed time until the temperature in the pulp chamber was stabilized was achieved. When the temperature was near the initial room temperature degrees (22 °C), the placement of composite resin was started, and the temperature increase was recorded in real-time by J type thermocouple. The difference between the initial and the last temperature recorded in the pulp chamber was calculated. These experiments were performed on the same samples as Group 4 (Figures 2 and 3).

Statistical Analyses

All statistical analyses were performed using version 23 of the SPSS software (Statistical Package for the Social Sciences for Windows 13.0, IBM Inc., Chicago, IL, USA). According to the results of the Shapiro-Wilk normality test, the data did not show a normal distribution. Kruskal Wallis test was used for the comparison of the differences in temperature changes. The Mann-Whitney U Test was used as a post-hoc test for multiple comparisons. The level of statistical significance was accepted as $p<0.05$.

Figure 2. Schematized design of the remaining dentine thickness of each group.

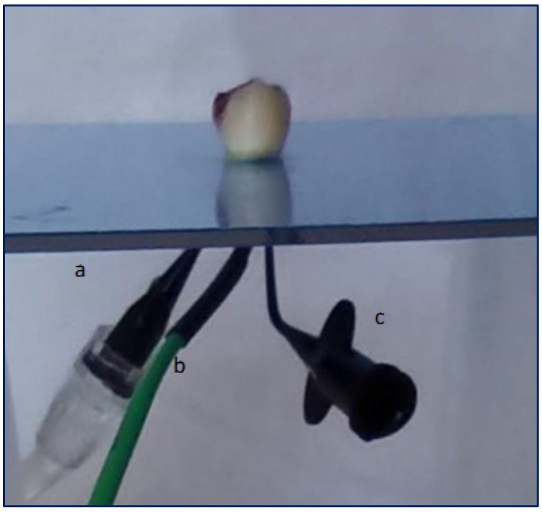

Figure 3. Image of the tooth sample in pulpal circulation model: a) Needle for feeding by water, b) Needle for extraction of the excess water, and c) The probe of the J type thermocouple.

Results

The findings of the temperature changes regarding different dentine thicknesses and glass ionomer liner applications in immature permanent molars are shown in Tables 2 and 3. Accordingly, a statistical difference was detected between the values of Group 1 and Group 2. The temperature increase in the group of 1 mm remaining dentin thickness revealed higher results compared to the values detected from the 2 mm group (1.01 °C) (p=0.00) (Table 2).

Table 2. Descriptive values of the groups compared.

Groups	N	Mean (°C)	SD	Minimum (°C)	Maximum (°C)	p-value
G 1	10	2.210	0.42282	1.10	2.50	0.00*
G 2	10	1.010	0.41486	0.50	1.70	
G 3	10	1.490	0.45080	0.50	1.90	0.011*
G 4	10	1.040	0.27568	0.60	1.40	
G 5	10	1.000	0.23094	0.60	1.50	0.196
G 6	10	0.860	0.43767	0.10	1.60	

*Statistically Significant; SD: Standard Deviation.

The values of Group 1 were statistically higher than the temperature increase determined in Group 3 (1.49) (p= 0.033) and Group 5 (1.00) (p=0.00). No statistical difference was detected between Group 3 (1.49) and Group 5 (1.00) (p>0.05). Also, Group 3 (1.49) revealed higher results compared to Group 4 (1.040) (p=0.011). On the other hand, no statistical difference was detected in the comparison of Group 2 (1.010), Group 4 (1.040), and Group 6 (0.860) (p>0.05) (Table 3).

Table 3. The p-values detected in the study groups.

Groups	Group 2	Group 3	Group 4	Group 5	Group 6
G 1	0.00	0.033	N.C	0.00	N.C
G 2	-	N.C	>0.05	N.C	>0.05
G 3	N.C	-	0.011	>0.05	N.C
G 4	>0.05	0.011	-	N.C	>0.05
G 5	N.C	>0.05	N.C	-	>0.05

N.C: Non compar.

Discussion

The primary outcome of the present study revealed that as the remaining dentine thickness was decreased, the heat conducted through the dentine tissue and the temperature in the pulp chamber increased. The temperature changes due to the exothermic polymerization reaction of glass ionomer cement were lower than the values determined in the polymerization process of resin composites with light-emitting diode (LED) devices in each dentine thickness, accordingly, the first hypothesis was accepted. However, a statistical difference was not detected in all groups wherein a glass ionomer application was preferred or not, which caused the rejection of the second statement of the hypotheses of the current study.

Maintaining the pulp vitality, especially in immature teeth with open apices, is essential in pediatric dentistry practices. Pulp tissue maintains the circulation, nutrition, and development of teeth. The extensive lesions or the treatment procedures recruited to manage the carious lesions may be a potential threat to the vitality of the pulp. When the pulp is affected irreversibly, in many cases, root canal treatment is indicated which is also a challenging procedure in teeth with open apices [15,16]. Although preventive approaches have been utilized in pediatric dentistry, it is also essential to minimize the harmful effect of treatment procedures on the pulp tissue especially in immature teeth. Accordingly, the current *in-vitro* study aimed to analyze the effect of different remaining dentin thicknesses and restorative materials on the thermal changes of the pulp chamber of immature permanent molars.

According to the results of the current study, in the group of 2 mm remaining dentine thickness, the temperature changes in the pulp chamber during the polymerization of glass ionomer and the composite resin following the glass ionomer liner application/without liner did not reveal statistical differences. However, in the group of 1 mm remaining dentine thickness, the changes in the pulp chamber's temperature showed differences, while the polymerization of glass ionomer cement and the resin composite following the glass ionomer liner/without liner occurred. This difference may be attributed to the effect of the 2 mm thickness of the remaining dentine tissue. This thickness of dentine is an adequate barrier for protecting the pulp from the adverse effect of heat conduction, and no additional protective liner is essential, even for immature teeth with open apex.

The changes in temperature of the pulp chamber could be analyzed by various methods, for example, infrared cameras, calorimeters, different thermal analyses, and thermocouples [10,17]. In this study, J J-type thermocouple was preferred due to the feature of the device that lets to assess the temperature changes of a surface directly. Considering the absence of blood, dentine fluid flow, and periodontal tissues, it can be concluded that *in-vitro* overestimation of the pulp temperature changes is probable [18,19]. However, to overcome this problem and based on the knowledge that pulpal microcirculation plays an essential role in eliminating the pulp temperature increase, a pulpal microcirculation mechanism was simulated in the extracted tooth samples [10,11]. In some of the studies, the saline solution and deionized water were placed in a thermal bath at 37°C [10,14,20], and the room temperature was chosen in the others [12,21]. Accordingly, considering the focus of the current study that aims to enlighten the differences in the pulp temperatures, deionized water at room temperature (22 °C) was preferred to be used. The flow rate of the water was arranged in 1ml/min and a serum injection system was settled for this purpose according to previous studies [10,11]. The standardization of cavity borders was obtained by affixing 4×5 mm stickers on the occlusal surfaces. In the groups with liners, glass ionomer was placed 2 mm thickness from the cavity floor. This thickness was determined by measuring with a caliper.

Previously, the adverse effects of the exothermic polymerization reactions were investigated in a few studies, and Zach and Cohen [6] reported that the critical degree that may lead to pulpal damage was 5.6 °C. In the current study, the highest temperature change was detected as 2.5 °C in the group of 1 mm remaining dentin thickness without glass ionomer liner application and even this higher degree detected in the current study was far below the critical degree that poses a risk for the irreversible pulp damages.

In the literature review, no study was detected assessing the pulpal temperature changes of immature teeth with open apex. However, Buyukkok and Kaptan [10] conducted a study in which they evaluated the temperature increases in the pulp chamber of extracted primary teeth during the polymerization of different glass ionomer-based materials and glass carbomer in a remaining dentine thickness of 1 mm and 2 mm. The results revealed that the heat conducted during the polymerization process of the materials was higher in the group of 1 mm remaining dentine thickness than in the group of 2 mm [10]. Although the study was conducted on extracted primary molars, the results were similar to the findings of the current study we held, and the results of the current study supported the outcomes of this previous study by enlightening the effect of remaining dentine tissue in the heat conduction through to the pulp in teeth with open apices.

In an *ex-vivo* study, dentine slices of different thicknesses were exposed to light curing devices, and the temperature changes were recorded at time intervals of 10 s, 20 s, 30 s, and 40 s [22]. Accordingly, as the dentin thickness decreased, an increase in the heat transmitted through the dentin disks was detected and these results were consistent with the current study. Another previous study [11] was conducted to assess the effect of the fluorescence-aided caries excavation (FACE) system and the remaining dentin thickness on the temperature changes of the pulp chamber. FACE system was performed in different remaining dentin thicknesses (2, 1.5, 1, 0.5 mm) and the results revealed that parallel to the decrease in the distance between the cavity floor and pulp chamber, an increase in temperature changes was detected. However, these temperature changes were not meant to cause irreversible damage in the pulp chamber [11]. These results are also in line with the outcomes of the current study, which reported the relation between the remaining dentin thickness and thermal changes in the pulp.

Previously, Altan et al. [23] conducted a similar study and assessed the effect of setting and polymerization of different composite resins and high-viscosity glass ionomer cement on the pulp temperature changes of primary molars. Accordingly, the thermal changes were found to be similar in the group of high-viscosity glass ionomer cement and composite resins. This study was conducted in Class-2 cavities, and a high-viscosity glass ionomer cement was used; the difference in results of the current study and this previous one might be related to this. In another previous study, Gavic et al [24] assessed the heat conduction features of different commercial glass ionomer cement types and they concluded that the thermal changes related to the exothermal setting reaction of glass ionomer cement were low and these changes were most detectable in deep cavities compared to superficial ones. These outcomes support the results of the current study.

In the present study, 1 mm and 2 mm remaining dentine thickness was assessed and the results may lead to differences if the study was repeated with a remaining dentine thickness of less than 1 mm. One type of composite resin, glass ionomer cement, and one brand of curing device were used in the study. The results might also change in case the type of restorative materials, liners, and curing devices were enlarged. The distance between the tooth and the polymerization device was also standardized in the study. Differences in the distance between these two parameters might also affect the study findings. The present study was conducted on *in-vitro* conditions and a pulpal microcirculation model was tried to be obtained simulating the physiological activities of the pulp tissue. Although the conditions the same as *in-vivo* were tried to be created, different results may be obtained if the study was repeated in *in-vivo* conditions. These are the limitations of the present study. In this respect, further clinical studies may also be conducted.

Conclusion

Within the limitations of this *in-vitro* study, the results revealed that in a remaining dentin thickness of 1 mm, using a glass ionomer liner might be a useful effort for protecting the pulp tissue from the heat generated by polymerization devices and conducted by the composite resin/remaining dentine tissue. In a case in which the remaining dentine is 2 mm and more, using a glass ionomer liner as a heat protector could be a useless effort, though the heat conducted in this dentine thickness was the same in the groups with and without liner. However, the current study was held on *ex-vivo* conditions and the described treatment modalities might lead to differences in clinical conditions. A real-time assessment of thermal changes could be performed clinically aimed to assess the intra-pulpal temperature changes of immature molars of the pediatric population in future studies.

Authors' Contributions

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All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

Financial Support

None.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

References

[1] Mjör IA. Dentin permeability: The basis for understanding pulp reactions and adhesive technology. Braz Dent J 2009; 20(1):3-16. https://doi.org/10.1590/s0103-64402009000100001

[2] Kwon SJ, Park YJ, Jun SH, Ahn JS, Lee IB, Cho BH, et al. Thermal irritation of teeth during dental treatment procedures. Restor Dent Endod 2013; 38(3):105-112. https://doi.org/10.5395/rde.2013.38.3.105

[3] Linsuwanont P, Palamara JE, Messer HH. An investigation of thermal stimulation in intact teeth. Arch Oral Biol 2007; 52(3):218-227. https://doi.org/10.1016/j.archoralbio.2006.10.009

[4] Le Fur-Bonnabesse A, Bodéré C, Hélou C, Chevalier V, Goulet JP. Dental pain induced by an ambient thermal differential: Pathophysiological hypothesis. J Pain Res 2017; 10:2845-2851. https://doi.org/10.2147/jpr.s142539

[5] Lau XE, Liu X, Chua H, Wang WJ, Dias M, Choi JJE. Heat generated during dental treatments affecting intrapulpal temperature: A review. Clin Oral Investig 2023; 27(5):2277-2297. https://doi.org/10.1007/s00784-023-04951-1

[6] Zach L, Cohen G. Pulp response to externally applied heat. Oral Surg Oral Med Oral Pathol 1965; 19:515-530. https://doi.org/10.1016/0030-4220(65)90015-0

[7] Daronch M, Rueggeberg FA, Hall G, De Goes MF. Effect of composite temperature on in vitro intrapulpal temperature rise. Dent Mater 2007; 23(10):1283-1288. https://doi.org/10.1016/j.dental.2006.11.024

[8] Hannig M, Bott B. In-vitro pulp chamber temperature rise during composite resin polymerization with various light-curing sources. Dent Mater 1999; 15(4):275-281. https://doi.org/10.1016/s0109-5641(99)00047-0

[9] Vernon JJ, Lancaster PE, Black EVI, Devine DA, Fletcher L, Wood DJ, et al. Increased handpiece speeds without air coolant: Aerosols and thermal impact. J Dent Res 2023; 102(1):53-60. https://doi.org/10.1177/00220345221123253

[10] Buyukkok C, Kaptan A. Temperature increases in primary teeth pulp chamber during polymerization of glass ionomer-based restorative materials. Eur Oral Res 2021; 55(1):28-33. https://doi.org/10.26650/eor.20210024

[11] Aksoy M, Şen S, Kaptan A, Büyükkok Ç, Tulga-Öz F. Does the heat generated by fluorescence-aided caries excavation system effect the pulp temperature of primary teeth irreversibly? An in-vitro evaluation of the temperature changes in the pulp chamber. J Clin Exp Dent 2021; 13(11):e1096-e1103. https://doi.org/10.26650/eor.20210024

[12] Savas S, Botsali MS, Kucukyilmaz E, Sari T. Evaluation of temperature changes in the pulp chamber during polymerization of light-cured pulp-capping materials by using a VALO LED light curing unit at different curing distances. Dent Mater J 2014; 33(6):764-769. https://doi.org/10.4012/dmj.2013-274

[13] Dikmen, B. ICDAS II criteria (international caries detection and assessment system). JIUFD 2015; 49(3):63-72. https://doi.org/10.17096/jiufd.38691

[14] Kodonas K, Gogos C, Tziafas D. Effect of simulated pulpal micro- circulation on intrapulpal temperature changes following application of heat on tooth surfaces. Int Endod J 2009; 42(3):247-252. https://doi.org/10.1111/j.1365-2591.2008.01508.x

[15] Abu-Tahun I, Torabinejad M. Management of teeth with vital pulps and open apices. Endod Topics 2010; 23(1):79-104. https://doi.org/10.1111/j.1601-1546.2012.00287.x

[16] Gatón-Hernandéz P, Serrano CR, da Silva LAB, de Castañeda ER, da Silva RAB, Pucinelli CM, et al. Minimally interventive restorative care of teeth with molar incisor hypomineralization and open apex—A 24-month longitudinal study. Int J Paediatr Dent 2020; 30(1):4-10. https://doi.org/10.1111/ipd.12581

[17] Guiraldo RD, Consani S, Lympius T, Schneider LF, Sinhoreti MA, Correr-Sobrinho L. Influence of the light curing unit and thickness of residual dentin on generation of heat during composite photoactivation. J Oral Sci 2008; 50(2):137-142. https://doi.org/10.2334/josnusd.50.137

[18] Altintas SH, Yondem I, Tak O, Usumez A. Temperature rise during polymerization of three different provisional materials. Clin Oral Investig 2008; 12(3):283-286. https://doi.org/10.1007/s00784-007-0163-7

[19] Kells BE, Kennedy JG, Biagioni PA, Lamey PJ. Computerized infrared thermographic imaging and pulpal blood flow: Part 1. A protocol for thermal imaging of human teeth. Int Endod J 2000; 33(5):442-447. https://doi.org/10.1046/j.1365-2591.2000.00257.x

[20] Akarsu S, Aktuğ Karademir S. Influence of bulk-fill composites, polimerization modes, and remaining dentin thickness on intrapulpal temperature rise. Biomed Res Int 2019; 2019:4250284. https://doi.org/10.1155/2019/4250284

[21] Ramoglu SI, Karamehmetoglu H, Sari T, Usumez S. Temperature rise caused in the pulp chamber under simulated intrapulpal microcirculation with different light-curing modes. Angle Orthod 2015; 85(3):381-385. https://doi.org/10.2319/030814-164.1

[22] Lynch CD, Roberts JL, Al-Shehri A, Milward PJ, Sloan AJ. An ex-vivo model to determine dental pulp responses to heat and light-curing of dental restorative materials. J Dent 2018; 79:11-18. https://doi.org/10.1016/j.jdent.2018.08.014
[23] Altan H, Göztas Z, Arslanoglu Z. Bulk-Fill restorative materials in primary tooth: An intrapulpal temperature changes study. Contemp Clin Dent 2018; 9(Suppl 1):S52-S57 https://doi.org/10.4103/ccd.ccd_23_18
[24] Gavic L, Gorseta K, Glavina D, Czarnecka B, Nicholson JW. Heat transfer properties and thermal cure of glass-ionomer dental cements. J Mater Sci Mater Med 2015; 26(10):249 https://doi.org/10.1007/s10856-015-5578-0