The effect of current pulp capping materials against intrapulpal temperature increase in primary teeth. An in-vitro study by pulpal microcirculation simulation model

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Abstract  Background/purpose: Widespread use of light-cured materials has raised the issue of possible thermal effects on pulp tissue. It was aimed to investigate the effectiveness of pulp capping materials (PCM) against intrapulpal temperature increases (ITI) in primary teeth during light-curing of componers in this study.

Materials and methods: A Class-I cavity was prepared on the primary mandibular second molar tooth. An experimental mechanism was used for pulpal microcirculation and temperature regulation of the tooth. There are eight groups in the study: in Groups 1–6: MTA-Angelus, Biodentine, Theracal LC, Dycal, conventional Glass Ionomer Cement (GIC) and resin-modified GIC were used as PCM, respectively. In Group-7 no PCM was used. In Group-8 only light was applied to the cavity without any PCM or compomer. Componer restorations were applied in Groups 1–7 with the same material (Dyract XP, DENTSPLY, Weybridge, UK) and light cured for 10sec with the same light-curing unit (Kerr, Demi Plus, 1200 mW/cm²). Temperature changes (Δt) in the pulp chamber were measured and statistically analysed with Kruskal–Wallis and Mann Whitney U tests.

Results: The highest Δt-value (4.57 ± 0.11°C) was measured in Group-4 and 7. The lowest Δt-value (3.94 ± 0.4°C) was measured in Group-8. Δt-values measured in the Groups 2, 3 and 6 were significantly lower than the values measured in Group-4 and 7 (p = 0.001). ITI during the light-curing of the PCM used in Group-3 and 6 exceeded the critical value (5.5°C) reported in the literature.

Conclusion: In protecting the pulp from the harmful thermal effects of restorative procedures Biodentine which is a self-cured material, may be most acceptable choice as an indirect PCM.
Introduction

In modern pediatric dentistry, through the use of light-cured resin-containing filling materials such as polyacid-modified composite resins (compomer restoratives), satisfactory restorations in terms of both physical and esthetical properties may be achieved in primary teeth. However, the widespread use of resin-containing materials has raised the issue of their possible chemical and thermal damaging effects on primary tooth pulp vitality, especially in deep cavities. To protect the pulp tissue from these harmful effects, the development and use of appropriate base materials is indispensable. Besides conventional glass ionomer cements and poly-carboxylate cements, current pulp capping materials such as resin-modified glass ionomer cements, mineral trioxide aggregate (MTA), bioactive dentine substitutes (Biodentine), and resin-modified calcium silicate cements (TheraCal LC) are reported to have been applied successfully as base materials under compomer restoratives that are frequently used in the restoration of primary teeth.1–4

During the polymerization of light-cured resin-containing filling materials, temperature increase occurs in the pulp tissue owing to both the exothermic reaction of the material and energy released from the light-curing unit (LCU).5,6 In current studies, attempts have been made to investigate these temperature increases in the pulp tissue during the light-curing process of the resin containing materials via in-vitro experimental setups that simulate the physiological body temperature and pulpal microcirculation.7–10 Almost all studies on this subject are related to the light curing process of composite resins and unfortunately there is not enough information about the changes in the primary tooth pulp temperature during light curing process of compomer materials which are widely used in pediatric dentistry because of their ability to prevent secondary caries via fluoride release and recharge features, similar physical properties to the primary tooth structure and sufficient aesthetic appearance. In addition to the extent of harmful thermal effects of light-curing process of compomer materials on primary tooth pulp, the effect of the pulp capping materials to protect the pulp against these temperature increases is even now a matter of interest.

The aim of this study is the in-vitro investigation of the temperature changes occurring in the pulp chamber during the polymerization of the compomer restorations when current pulp capping materials are applied to the cavity base of the primary teeth. The null hypothesis attempts to show that 1) there would be no difference in the temperature increase in the pulp chamber during the curing of compomer material, with and without the use of different base materials, 2) there would be a difference in intrapulpal temperature rise during the curing of compomer material depending on whether a light-curing base material or a self-curing base material is used 3) the temperature increase in the pulp chamber during the curing of light-cured base materials would exceed the critical temperature value (5.5°C).

Materials and methods

Ethical approval of the study was obtained from the Human Ethical Committee of the Local Medicine Faculty on September 25th, 2018 with the reference number 65028.

Preparation of the specimens

Freshly extracted mandibular second primary molar teeth were collected and stored in 0.1% thymol solution up to the beginning of the study. In order to avoid morphological and structural differences due to the use of multiple teeth in the experiments, all the measurements were carried out on a single primary tooth sample model. A Class I cavity with 2 mm depth and 1 mm pulpal wall thickness was prepared on the primary mandibular second molar tooth (Fig. 1). The thickness of the pulpal dentin wall was determined via a caliper and radiographic examination. The roots were separated 1 mm below the cement-enamel junction perpendicular to the long axis. The remnant pulpal tissues were removed with an excavator and the pulp chamber was irrigated with distilled water and dried with air. In order to insert a thermocouple, the entrance to the pulp chamber was prepared as required (Fig. 1).

Study design

Into the pulp chamber of primary second molar tooth, a K-type thermocouple (TT-K-30-SLE, Omega Engineering Inc., Stamford, CT, USA) was located in contact with the pulp ceiling with the thermal grease (ZM-STG2, Zalman Tech Co. Ltd., Dongan-gu, South Korea) (Fig. 1). The space around the thermocouple wire was filled with the resin-modified glass ionomer cement (Ionoseal, Voco, Cuxhaven, Germany) to avoid leakage from the system. The thermocouple cable was connected to a data logger (DT-3891G, CEM, Shenzhen, PRC) that was connected to a computer; in this way, temperature changes (Δt) were monitored.

An experimental mechanism (Fig. 1) was used for pulpal blood microcirculation and temperature regulation of the tooth within the physiological limits (37 ± 1°C). The prepared primary second molar tooth was fixed on the temperature-controlled aluminum base plate (TCAP) using the resin-modified glass ionomer cement (Ionoseal, Voco, Cuxhaven, Germany). Two 25-gauge needles (8695659000777, Hayat Medical Co., Istanbul, Turkey) were placed into the pulp chamber of the tooth through the hole of the TCAP to create pulpal microcirculations and were used for distilled water inflow and outflow ways (Fig. 1). The distilled water was
flowed with a rate of 0.0125 ml/min through the pulp chamber by using an infusion pump set (IP12A, Biocare, Shenzhen, PRC) (Fig. 1). A 4-mm-diameter spiral shaped copper tube was attached under the TCAP in order to maintain the physiological temperature \(37 \pm 1^\circ C\) in the pulp chamber, and was connected to the water bath with a standard infusion set (Fig. 2).

In the study, there are six groups (Groups 1–6) wherein the base material and the compomer restorations were applied to the cavity, one group (Group 7) wherein the direct compomer restorations were applied without any base material, and one group (Group 8) wherein only light was applied to the Class I cavity without any base material or compomer restoration. As the experiments were carried out on a single tooth model, adhesive resin was not applied to the cavity in order to make repetitive compomer restorations.

In all the restoration groups (Groups 1–7), ten repetitive compomer restorations were applied with the same material (Dyract XP, DENTSPLY) and the light-cured each for 10 s according to the instructions of the manufacturer with the same light-curing unit (Kerr, Demi Plus, 1200 mW/cm²). Base materials and compomer restoratives that were used in the present study are listed in Table 1.

Figure 1 Schematic drawing of the primary second molar tooth and Class I cavity with experimental pulp microcirculation model.

Figure 2 Bottom view of the temperature-controlled aluminum base plate (TCAP), which is part of the experimental apparatus to regulate the tooth physiological temperature.
Table 1 Details of the materials used in the study.

| Groups (Base materials) | Materials          | Manufacturer                  | Product description                          | Curing/Setting type |
|-------------------------|--------------------|-------------------------------|---------------------------------------------|--------------------|
| Group 1                 | MTA                | Angelus dental solutions, Ltd | Mineral Trioxide Aggregate reperative cement | Self-cured         |
| Group 2                 | Biodentine         | Septodont, Saint-Maur-des-Fossés, France | Bioactive dentine substitute                | Self-cured         |
| Group 3                 | TheraCal LC       | Bisco Inc, Schaumburg, IL, USA | Resin-modified calcium Silicate pulp protectant/liner | Light-cured        |
| Group 4                 | Dycal              | Dentsply, Milford, DE, USA    | Radiopaque calcium hydroxide composition    | Self-cured         |
| Group 5                 | Ketac Molar Easymix | 3M ESPE, St. Paul, MN, USA   | Conventional glass ionomer cement           | Self-cured         |
| Group 6                 | Ionoseal           | VOCO, Cuxhaven, Germany       | Light-curing radiopaque glass ionomer liner | Light-cured        |
| Group 1–7               | Dyract XP          | Dentsply, Weybridge, UK       | Polycad-modified composite resin (comomer)  | Light-cured        |

Intrapolpal temperature changes were evaluated while implementing the curing unit in the occlusal direction of the Class I cavity from a distance of 1 mm that was provided with a 1-mm-thick cover glass. All measurements were obtained at 37 ± 1°C, only during the light-curing process of the compomers. For the light-cured base materials (Theracal LC and resin-modified GIC) in Groups 3 and 6, pulpal temperature measurements were obtained during the polymerization of the base material as well; thus, in these groups pulpal temperature changes were measured twice. The differences between the initial and maximum temperatures (Δt) measured in the pulp chamber during the curing of ten repetitive compomer restorations in each group were recorded and the mean Δt values of the groups were compared.

Statistical analysis

The statistical analyses were performed in the IBM SPSS Software (SPSS v23.0, SPSS Inc., Chicago, IL, USA). The Shapiro–Wilk omnibus test was used for assessment of normality of the data. The Mann Whitney U test for the paired comparisons and the Kruskal–Wallis test for multiple comparisons were used and the differences of the temperature changes between the groups were analyzed at a significance level of p ≤ 0.05.

Results

In this study, totally 80 pulpal temperature increases were measured in eight groups. The highest value of the pulpal temperature increase (4.57 ± 0.11°C) was measured in Group 4 wherein Dycal was applied as the base material and in Group 7 (4.57 ± 0.1°C) wherein the direct compomer restorations were made without any base materials. The lowest temperature increase value (3.94 ± 0.4°C) was measured in Group 8 wherein only light was applied to the Class I cavity without any base material or compomer restoration.

Among the base material applied groups, the lowest intrapolpal temperature increase (4.01 ± 0.29°C) was measured in Group 6 wherein the resin-modified GIC was applied.

Temperature increase values measured in the groups wherein Biodentine, Theracal LC, and the resin-modified GIC were applied were significantly lower than the values measured in Groups 4 and 7 (p = 0.001).

Temperature increases during the polymerization of the light-cured base materials used in Groups 3 and 6 were measured as 5.97 ± 0.48°C and 6.31 ± 0.54°C, respectively. Mean Δt value measured during the curing of Theracal LC was found to be lower than the mean Δt value of the resin-modified GIC; however, the difference between the two materials was not statistically significant (p = 0.237). Since the data of the study did not show normal distribution, the median values of the groups and their differences are summarized in Table 2.

Discussion

Temperature increase during the curing of restorative materials is attributed to both the exothermic polymerization of materials and the energy absorbed from the LCU during the irradiation period.2,6 It was observed that the lowest mean intrapolpal temperature increase was measured in

Table 2 Differences between median values of intrapolpal temperature increases of the groups.

| Groups (Base materials) | Median (min—max) |
|-------------------------|-------------------|
| Group 1 (MTA)           | 4.2 (4—4.5)ab     |
| Group 2 (Biodentine)    | 4.1 (3.2—4.6)a    |
| Group 3 (Theracal LC)   | 4.1 (3.4—4.6)a    |
| Group 4 (Dycal)         | 4.6 (4.4—4.7)b    |
| Group 5 (Conventional GIC) | 4.3 (3.8—4.4)ab |
| Group 6 (Resin-modified GIC) | 4.1 (3.5—4.4)a |
| Group 7 (Direct compomer restoration) | 4.6 (4.4—4.7)b |
| Group 8 (No base material or restoration) | 3.9 (3.4—4.4)a |

GIC: Glass ionomer cement. The median values indicated by a and b are statistically significantly different from each other (p = 0.001) and ab is not significantly different from the values indicated by a and b (p > 0.05).
Group 8 wherein no base materials or compomer restorations were applied to the cavity. This finding verifies that the heat generated by the exothermic reaction of the resin-containing material plays an active role in the increase of the intrapulpal temperature.

Although dentine has a relatively low thermal conductivity, it is assumed that the heat transmitted to the pulp tissue is greater in deep cavities where the remaining dentin thickness is slight and the tubular surface is increased, especially in primary teeth.11–13 Thus, in the present study, in order to generate a deep cavity form, the distance between the tip of the thermocouple and cavity floor of the sample tooth was 1 mm.

During the light curing of the compomer restorations, it was observed that there was no difference between the mean intrapulpal temperature increase values of Group 4 wherein Dycal was applied to the cavity as a base material, and Group 7 wherein no base material was used. Conversely, all the other base materials used in this study played a protective role against intrapulpal temperature increase that occurs during the polymerization of compomer restoratives.

The lowest temperature increase in the pulp chamber during the curing of compomer restoration was not occurred when a self-cured pulp capping agent was used as expected at the beginning of the study, it was occurred when the resin-modified GIC was applied.

The mean intrapulpal temperature increase during the polymerization of the compomer material did not exceed 5.5 °C in any of the groups in this study, which is reported by Zach and Cohen (1965) as the critical temperature increase for irreversible pulp damage.14 This may be owing to the short irradiation time of 10 s of the compomer material used in this study. On the other hand, during the polymerization of the light-cured base materials (TheraCal LC and resin-modified GIC), which required 20 s irradiation time, the temperature increase in the pulp chamber exceeded the critical value. This may be due to the increase in the intrapulpal temperature with the increase in irradiation time as indicated in the literature.15 However, these findings suggest that the application of the self-cured materials such as Biodentine, MTA, and conventional GIC, rather than the light-cured base materials under the compomer restorations, would be more reliable against intrapulpal temperature due to lack of light-curing requirements.

It is possible to obtain various studies reporting the advantages and disadvantages of current base materials.1,3,4,16,17 However, it is not apparent yet which material may be used as ideal indirect pulp capping material in pediatric dentistry, especially for primary teeth. Studies investigating the efficacy of current pulp capping materials to protect the pulp tissue from the harmful thermal effects of restorative procedures are very limited. In the study of Savaş et al. (2014), temperature changes occurring in permanent dental pulp were examined during the polymerization of the light-cured pulp capping materials, and it was reported that TheraCal LC is the material that causes the lowest temperature increase in pulp during its polymerization process.7

In a study that investigating the material choices of clinicians for indirect pulp capping, it was reported that despite its high success rates as a pulp capping agent, MTA is not widely preferred by clinicians in pediatric dentistry.18 The high cost of the material and inadequate knowledge regarding the procedure to use MTA are considered as possible barriers to its common usage.19 In the present study, although MTA was not significantly successful as Biodentine, TheraCal LC and resin-modified GIC, pulpal temperature increase did not reach the critical value (5.5 °C) when MTA was used as an indirect pulp capping agent.

In recent years, it has been shown that calcium-silicate-based materials such as TheraCal LC and Biodentine can be used successfully as indirect pulp capping materials under resin restorations because of their stimulations of hard tissue formation and ion-releasing abilities.2–4,20 TheraCal LC performs as an insulator and protector of the dentin-pulp complex. The formulation of TheraCal LC consists of tricalcium silicate particles in a hydrophilic monomer that provides significant calcium release that stimulates hydroxyapatite and secondary dentin bridge formation making it a uniquely stable and durable base material. Gandolfi et al. (2015) concluded that TheraCal LC displayed higher calcium releasing ability and lower solubility than either ProRoot MTA or Dycal.17 In addition, several superior properties of Biodentine are mentioned in literatures such as material handling, faster setting time, biocompatibility, stability, increased compressive strength, increased density, decreased porosity, tight sealing properties, and early form of reparative dentin synthesis.21–22 Thus, Biodentine has been reported to be much more cost effective in comparison to other similar materials.21–23 Likewise, in the present study, Biodentine was found to be one of the most successful base materials to protect the pulp from the temperature increase during the light-curing process of restorative materials.

The temperature increases obtained in this in vitro study, unfortunately, do not directly reflect the values that occur in vivo procedures. Temperatures exceeding 43 °C stimulate the afferent nerve fibers and cause an increase in blood circulation so that the temperature moving towards the pulp chamber is distributed.24 Also, other heat regulatory systems of the teeth as fluid motion in dentinal tubules or cooling effect of surrounding periodontal tissues and saliva may limit the increase in intrapulpal temperature. These factors can be considered as limitations of this study. Nevertheless, a current study evaluated how similar an in vivo model is able to reproduce temperature increase values compared to the in vitro model, in anesthetized intact, unrestored, human upper premolars, in order to validate the in vitro methodology.24 Runnacles et al. (2017) reported that, in vitro pulp temperature increase values were close to in vivo values when clinically relevant exposure modes were delivered.25 Since the ethical problems in front of such in-vivo studies and the findings of Runnacles et al., in-vitro studies that evaluate the temperature increase in pulp chamber are still valid. In our knowledge, it is the first study about intrapulpal temperature increases during light-curing of compomer restorations in primary teeth and the protective effects of current pulp capping materials against these temperature increases. Clinicians even treating the primary teeth should be aware of the possibility of damage due to a temperature increase in the pulp chamber during light activated polymerization process.
of compomer restoratives and light-cured pulp capping agents.

It was observed that when the resin-modified GIC, TheraCal LC, and Biodentine materials were used for indirect pulp capping, there were statistically lower temperature increases in the primary tooth pulp chamber during the polymerization of compomer restoratives. However, the light-curing process of resin-modified GIC and TheraCal LC materials caused intrapulpal temperature increase that exceeded the critical value, thus Biodentine which is a self-cured material, was found to be more reliable in protecting the primary tooth pulp from the harmful thermal effects of light-curing process of compomer restorations.

Declaration of Competing Interest

The authors have no conflicts of interest relevant to this article.

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References

1. Allazzam SM, Alamoudi MN, El Meligy OAS. Clinical applications of biodentine in pediatric dentistry: a review of literature. J Oral Hyg Health 2015;3:1–6.
2. Raskin A, Eschrich G, Dejou J, About I. In vitro microleakage of Biodentine as a dentin substitute compared to Fuji II LC in cervical lining restorations. J Adhesive Dent 2012;14:535–42.
3. Kurun Aksoy M, Tulga Oz F, Orhan K. Evaluation of calcium (Ca2+) and hydroxide (OH−) ion diffusion rates of indirect pulp capping materials. Int J Artif Organs 2017;40:641–6.
4. Qureshi A, Soujanya E, Nandakumar Pratap Kumar, SambasivaraO. Recent advances in pulp capping materials: an overview. J Clin Diagn Res 2014;8:316–21.
5. Lloyd CH, Joshi A, McGlynn E. Temperature rises produced by light sources and composites during curing. Dent Mater 1986;2:170–4.
6. Shortall AC, Harrington E. Temperature rise during polymerization of light-activated resin composites. J Oral Rehabil 1998;25:908–13.
7. Savas S, Botsali MS, Kucukyilmaz E, San 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;33:764–9.
8. Yaşşa E, Atalayın C, Karacolak G, San T, Türkan LS. Intrapulpal temperature changes during curing of different bulk-fill restorative materials. Dent Mater J 2017;36:566–72.
9. Baroudi K, Silikas N, Watts DC. In vitro pulp chamber temperature rise from irradiation and exotherm of flowable composites. Int J Paediatr Dent 2009;19:48–54.
10. Ramoglu SI, Karamehmetoglu H, San T, Usumez S. Temperature rise caused in the pulp chamber under simulated intrapulpal microcirculation with different light-curing modes. Angle Orthod 2015;85:381–5.
11. Al-Qudhah AA, Mitchell CA, Biagioni PA, Hussey DL. Thermo-graphic investigation of contemporary resin containing dental materials. J Dent 2005;33:593–602.
12. Nör JE, Feigl RJ, Dennison JB, Edwards CA. Dentin bonding: SEM comparison of the resin–dentin interface in primary and permanent teeth. J Dent Res 1996;75:1396–403.
13. McGuirk RS, Tao I, Thompson WO, Pashley DH. Shear bond strength of Scotchbond in vivo. Dent Mater 1990;7:50–3.
14. Zach L, Cohen G. Pulp response to externally applied heat. Oral Surg Oral Med Oral Pathol 1965;19:515–30.
15. Hannig M, Bott B. In-vitro pulp chamber temperature rise during composite resin polymerization with various lightcuring sources. Dent Mater 1999;15:275–81.
16. Komabayashi T, Zhu Q, Eberhart R, Imai Y. Current status of direct pulp-capping materials for permanent teeth. Dent Mater J 2016;35:1–12.
17. Gandolfi MG, Siboni F, Botero T, Bossù M, Ricciitiello F, Prati C. Calcium silicate and calcium hydroxide materials for pulp capping: biointeractivity, porosity, solubility and bioactivity of current formulations. J Appl Biomater Funct Mater 2015;13:43–60.
18. Ha NW, Kahler B, Walsh LJ. Dental material choices for pulp therapy in paediatric dentistry. Eur Endod J 2017;2:1–7.
19. Foley JI. A pan-European comparison of the use of mineral trioxide aggregate (MTA) by postgraduates in paediatric dentistry. Eur Arch Paediatr Dent 2013;14:113–6.
20. Koubi G, Colan P, Franquin JC, et al. Clinical evaluation of the performance and safety of a new dentine substitute, Biodentine, in the restoration of posterior teeth - a prospective study. Clin Oral Invest 2013;17:243–9.
21. Zanini M, Sautier JM, Berdal A, Simon S. Biodentine induces immortalized murine pulp cell differentiation into odontoblast-like cells and stimulates biominalerization. J Endod 2012;38:1220–6.
22. Laurent P, Camps J, About I. Biodentine induces TGF-β1 microcirculation with different light-curing modes. J Adhesive Dent 2014;33:764–9.
23. Camilleri J, Grech L, Galea K, et al. Porosity and root dentine to material interface assessment of calcium silicate-based root-end filling materials. Clin Oral Investig 2014;18:1437–46.
24. Kaushik P, Arrais CAG, Maucoski C, Coelho U, De Goes MF, Ruegggeberg FA. Comparison of in vivo and in vitro models to evaluate pulp temperature rise during exposure to a Polywave® LED light curing unit. J Appl Oral Sci 2019;27:1–11.