Effect of thermocycling on the amount of monomer released from bulk fill composite resins

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The goal of this study was to examine the effect of thermal cycling on the amount of monomer released from bulk fill composites. Five bulk fill composite resins were used in the study. Extraction solutions were obtained at the end of the time/thermal cycle periods: 0–1 day/0–1,500, 1–3 days/1,500–4,500 and 3–7 days/4,500–10,000. The monomers in the extractions samples taken at each time point were measured on an HPLC instrument. The obtained data were analyzed by repeated measures of variance analysis and tukey multiple comparison tests (p<0.05). The thermocycling increased the amount of monomer released from all composites at 0–1 day (p<0.05). At 0–1 and 1–3 days, Venus Bulk Fill and Filtek Bulk Fill composite resins were more affected. Polymer networks with high molecular weight monomers such as Bis-GMA and UDMA can be less affected by thermal changes compared to polymers with low molecular weight monomers.

Keywords: Composite resins, Elution, HPLC, Residual monomer, Thermal cycling

INTRODUCTION

While the use of amalgam has significantly decreased in the last decade with the increase of esthetic requirements, there is an increase in the use of resin based composite (RBC) which are esthetically more compatible with tooth color and allowing minimally invasive treatment. Although RBCs are more preferred than other restorative materials because of compatible with tooth color; polymerisation shrinkage, weaker abrasion resistance, and residual monomers restrict their use¹⁻².

In RBCs, only 70–75% of the monomers can be polymerized⁶. Unpolymerized monomers can reach the systemic circulation through the digestive and respiratory system. These monomers in the systemic circulation may occur cytotoxic, mutagenic, genotoxic and estrogenic effects⁴⁻⁶. Also, the use of RBCs in the direct coating of the pulp can inhibit the formation of dentin bridges. Applied these resins can cause apoptosis or necrosis of the pulp cells⁷⁻⁸. In order to reduce these pathological effects on the patients, the amount of residual monomer released from the RBC should be reduced to the minimum.

The amount of conversion of the monomers to the polymers may vary depending on the internal factors such as the chemical structure of the monomers, the concentration of the reaction initiators, etc., as well as on the external factors such as polymerization conditions⁹. In RBCs, it is compulsory to limit the polymerization depth to be able to transmit light to the substrate. Many researchers have stated that the polymerization depth in conventional RBC should be 2 mm¹⁰⁻¹¹. In deeper cavities, this limitation requires that the RBCs be applied to the cavity in a layered manner¹². But the incremental technique has disadvantages such as the presence of voids between RBC layers, the risk of contamination between layers, failure in interlayer bonding, difficulty in application in small cavities and require more time for polymerization¹³. Bulk-fill RBCs, which can be applied as a single layer, have been produced to eliminate the workload and time required for layering and to enable better adaptation of the posterior RBCs. It is claimed by the manufacturers that these materials have a depth of polymerization of 4–5 mm².

RBCs are exposed to chemical, mechanical and thermal factors for a life period after they are restored. These factors impair the polymer structure of the RBCs and reduce the persistence period and mechanical and esthetic properties of the RBCs¹⁴⁻¹⁵. Although the oral temperature is accepted as 35.7–37.7°C in men and 33.2–38.1°C in women, these temperature values vary between 85°C and −12°C with foods such as coffee and ice cream in modern life¹⁶⁻¹⁷. The solvent materials diffuse easily through the microstructures which occurred because of thermal changes and this result in the increase of the amount of dissolution¹⁸. The thermal cycling process is an artificial ageing technique that simulates these thermal changes. Exposure of the materials to hot water during thermal cycling accelerates the hydrolysis of the components, which in turn increases the water absorption of the resin. With increased water absorption, an increase in the extraction of insufficiently polymerized resin oligomers and degraded products is observed¹⁹⁻²⁰.

Although there are studies examining the amount of monomer which has been eluted from bulk-fill RBCs in the literature, there is no study on how much extent thermal changes can affect the amount of residual monomer. The purpose of this study was to investigate...
the effect of thermal cycling on the amount of monomer eluted from bulk fill RBCs. The null hypothesis was: The increased the number of thermal cycles would not increase the amount of monomers eluted from tested RBCs.

MATERIALS AND METHODS

Specimen preparation

Five bulk fill RBCs were used: Filtek Bulk Fill Flowable (FBF), SonicFill 2 (SF), Tetric N-Ceram Bulk Fill (TB), SDR (SDR), and Venus Bulk Fill (VB). The technical details of the materials were presented in Table 1. Each RBC material was placed into circular teflon molds as a single increment to produce RBC samples at a depth of 4 mm. The teflon mold was compressed with a finger press between two microscopic slides to remove excess of the RBC specimens and to eliminate gaps. All materials were cured for 20 s with a light-emitting diode (VALO Cordless, Ultradent, South Jordan, UT, USA) light source at standart power mode (intensity 1,000 mW/cm²). This light source uses a custom, multiwavelength light-emitting diode for producing a high-intensity light at 395–480 nm. This light-emitting diode pack produces true broad-spectrum light, which provides uniform curing across the restoration with two significant peak wavelengths, utilizing two shades of blue and violet required for lower-level initiators. This means that source is capable of polymerizing all light-cured dental materials including camphorquinone and the entire range of proprietary photoinitiators. The output irradiance of the light source was checked using a calibrated radiometer at each use (TREE, model TR-P004, Foshan, Guangdong, China). After light-curing, specimens were pushed out from the molds with gentle pressure and excess materials were removed using a sharp blade. Ten specimens were fabricated from each material. Immediately after curing, each specimen was placed in a 2 mL amber-colored glass vial and covered with 1.5 mL 75% ethanol/water solution.

Glass vials included polymerized RBCs were separated into two groups: The thermocycling and the control group: All specimens in the control group were stored in an incubator (Memmert UN110, Schwabach, Germany) at 37°C. The glass vials in the thermocycling group were placed in a thermal cycler (Gokceler Makine, Sivas, Turkey), in which the temperatures were set at 5 and 55°C. The immersing time for each bath was 25 s and the interval time between baths was 7 s. Extraction solutions were obtained at the end of the time periods: 0–1 day (T1), 1–3 days (T2) and 3–7 days (T3). These time periods corresponded to the number of thermal cycles of 0–1,500 (T1), 1,500–4,500 (T2) and 4,500–10,000 (T3), respectively.

After filtration using 0.2 μm HPLC syringe filters (Minisart RC15, Sartorius Stedim Biotech, Goettingen, Germany), ethanol/water extraction solutions were collected in new glass vials for HPLC-DAD analysis.

Table 1  The technical details of the materials used in the study

| Composite       | Manufacturer                  | Shade | Lot number | Composition                                                                 | Filler (wt%–vol%) |
|-----------------|-------------------------------|-------|------------|-----------------------------------------------------------------------------|-------------------|
| Filtek Bulk     | 3M ESPE Dental Product, St. Paul, MN, USA | A2    | N752806    | Bis-GMA, Bis-EMA, TEGDMA, UDMA, silane treated ceramic filler, silane treated silica filler. Modified UDMA, TEGDMA, Bis-EMA, barium-alumino-fluoro-borosilicate glass, strontium alumino-fluoro-silicate glass, camphorquinone | 65–42.5           |
| Fill Flowable   |                               |       |            |                                                                             |                   |
| SDR             | Dentsply, Caulk, USA          | A2    | 11131      | Modified UDMA, TEGDMA, Bis-EMA, barium-alumino-fluoro borosilicate glass, strontium alumino-fluoro-silicate glass, camphorquinone | 68–44             |
| SonicFill 2     | Kerr, Orange, CA, USA         | A2    | 5823680    | Bis-GMA, TEGDMA, Bis-EMA, silicon dioxide, glass oxide, camphorquinone       | 83–NS             |
| Tetric N-Ceram  | Ivoclar Vivadent, Amherst, NY, USA | IVA   | T20645     | Bis-GMA, UDMA, Bis-EMA, barium aluminium silicate glass, ytterbium fluoride, ivocerin | 77–61             |
| Bulk Fill       | Heraus Kulzer, Germany        | Universal | 1238065 | UDMA, Bis-EMA, barium-alumina-fluoro-silica glass, silicon dioxide, ytterbium trifluoride, camphorquinone | 65–38             |

Bis-GMA: bisphenol-A-glycidyl dimethacrylate, Bis-EMA: ethoxylated bisphenol-A-dimethacrylate, UDMA: Urethane dimethacrylate, TEGDMA: triethyleneglycol dimethacrylate, NS: Not Specified
**Table 2** Mean (±SD) concentrations (μg/mL) of eluted Bis-GMA from RBCs over seven days

| Material | Control | Thermal cycle | T/C | Control | Thermal cycle | T/C | Control | Thermal cycle | T/C |
|----------|---------|---------------|-----|---------|---------------|-----|---------|---------------|-----|
| FBF      | 80.0(3.39)<sup>C</sup> | 98.2(4.44)<sup>Cd</sup> | 1.23 | 20.1(1.63)<sup>ba</sup> | 32.1(2.69)<sup>ab</sup> | 1.57 | 18.2(0.93)<sup>c</sup> | 33.6(2.65)<sup>cs</sup> | 1.85 |
| SDR      | 45.6(3.56)<sup>b</sup> | 67.2(1.8)<sup>b</sup> | 1.47 | 20.9(0.44)<sup>b</sup> | 28.9(0.71)<sup>b</sup> | 1.38 | 19.4(0.8)<sup>a</sup> | 38.2(1.18)<sup>bc</sup> | 1.97 |
| SF       | 50.5(4.15)<sup>b</sup> | 76.3(5.98)<sup>b</sup> | 1.51 | 19.3(3.71)<sup>ba</sup> | 23.7(2.16)<sup>b</sup> | 1.23 | 9.3(0.41)<sup>b</sup> | 30.4(1.59)<sup>bc</sup> | 3.26 |
| TB       | 282(9.66)<sup>b</sup> | 322(6.39)<sup>b</sup> | 1.14 | 102(5.83)<sup>bc</sup> | 114(18.4)<sup>c</sup> | 1.12 | 92.0(5.51)<sup>b</sup> | 95.5(1.5)<sup>bc</sup> | 1.03 |
| VB       | 17.8(5.77)<sup>b</sup> | 36.3(2.36)<sup>b</sup> | 2.04 | 3.58(0.93)<sup>bc</sup> | 7.2(1.06)<sup>bc</sup> | 2.01 | 3.98(0.69)<sup>a</sup> | 7.78(0.95)<sup>bc</sup> | 1.95 |

Different uppercase letters indicate significant difference in the vertical column (p<0.05). Different lowercase letters indicate significant difference in the horizontal row (p<0.05). T/C: Thermal cycle/Control.
Table 3 Mean (±SD) concentrations (μg/mL) of eluted TEGDMA from RBCs over seven days

| Material | T1          | T2          | T3          |
|----------|-------------|-------------|-------------|
|          | Control     | Thermal cycle | T/C         | Control     | Thermal cycle | T/C         | Control     | Thermal cycle | T/C         |
| FBF      | ND          | ND          | —           | ND          | ND            | —           | ND          | ND            | —           |
| SDR      | 52.5 (3.8)Dc | 46.8 (1.9)Cc | 0.89        | 3.8 (0.6)Bb | 7.4 (0.8)Bb   | 1.95        | ND          | ND            | —           |
| SF       | 102.8 (2.5)Db | 138.8 (4.6)Da | 1.35        | 27.2 (6.5)Bb | 36.2 (2.3)Cc  | 1.33        | 21.1 (2.2)a  | 39.6 (1.9)c  | 1.88        |
| TB       | ND          | ND          | —           | ND          | ND            | —           | ND          | ND            | —           |
| VB       | 14.4 (2.3)Bb | 34.2 (2.4)Cc | 2.38        | 3.8 (0.7)Ab | ND            | —           | ND          | ND            | —           |

Different uppercase letters indicate significant difference in the vertical column (p<0.05). Different lowercase letters indicate significant difference in the horizontal row (p<0.05), T/C: Thermal cycle/Control, ND: Non-dedected.

Table 4 Mean (±SD) concentrations (μg/mL) of eluted UDMA from RBCs over seven days

| Material | T1          | T2          | T3          |
|----------|-------------|-------------|-------------|
|          | Control     | Thermal cycle | T/C         | Control     | Thermal cycle | T/C         | Control     | Thermal cycle | T/C         |
| FBF      | 264.0 (3.8)c | 365.5 (15.8)Db | 1.38        | 84.3 (7.5)Ba | 105.3 (2.4)Bb | 1.25        | 71.4 (3.93)Ba | 111.3 (3.6)Bb | 1.56        |
| SDR      | 288.6 (6.9)Cc | 310.7 (6.4)Cc | 1.08        | 117.6 (4.9)b | 129.9 (5.9)Bb | 1.10        | 103.7 (2.4)Ba | 117.8 (3.2)Cb | 1.14        |
| SF       | ND          | ND          | —           | ND          | ND            | —           | ND          | ND            | —           |
| TB       | 279.4 (10.0)c | 316.5 (6.3)Cc | 1.13        | 89.2 (4.1)Bb | 99.3 (6.7)Cc  | 1.11        | 71.9 (9)Ba   | 86.8 (2.1)Bb | 1.21        |
| VB       | 258.2 (8.0)Bc | 285.6 (3.0)Db | 1.11        | 25.8 (5)Ab  | 44.0 (2.8)Ab  | 1.71        | 16.6 (0.5)Ab  | 27.2 (0.9)Ab | 1.64        |

Different uppercase letters indicate significant difference in the vertical column (p<0.05). Different lowercase letters indicate significant difference in the horizontal row (p<0.05), T/C: Thermal cycle/Control, ND: Non-dedected.

Table 5 Mean (±SD) concentrations (μg/mL) of eluted Bis-EMA from RBCs over seven days

| Material | T1          | T2          | T3          |
|----------|-------------|-------------|-------------|
|          | Control     | Thermal cycle | T/C         | Control     | Thermal cycle | T/C         | Control     | Thermal cycle | T/C         |
| FBF      | 25.2 (1.6)Ac | 37.7 (3.3)Db | 1.50        | 9.6 (0.8)Ab | 18.3 (0.9)Ab  | 1.91        | ND          | ND            | —           |
| SDR      | 55.3 (7.8)Ca | 74.9 (4.7)Cb | 1.35        | ND          | ND            | —           | ND          | ND            | —           |
| SF       | 48.8 (8.9)Bb | 72.4 (4.2)Ce | 1.48        | 13.0 (4.6)Ab | 17.5 (1.4)c  | 1.35        | 4.9 (1.1)Bb  | 7.1 (1.3)Bb  | 1.45        |
| TB       | ND          | 25.6 (1.4)Ab | —           | ND          | ND            | —           | ND          | ND            | —           |
| VB       | 60.9 (8.7)Cc | 155 (2.3)Dc | 2.55        | 47.1 (5.5)Bb | 67.1 (0.8)Bb | 1.42        | 8.8 (2.5)Bb  | 11.6 (3.2)Bb | 1.32        |

Different uppercase letters indicate significant difference in the vertical column (p<0.05). Different lowercase letters indicate significant difference in the horizontal row (p<0.05), T/C: Thermal cycle/Control, ND: Non-dedected.
increased the amount of Bis-EMA released from all the RBCs significantly more than the control group (\(p<0.05\)), but only did not affect SF at T2 time interval (\(p>0.05\)). At the T3 time interval, the thermocycling did not affect the amount of Bis-EMA released from SF and VB statistically (\(p>0.05\)). At T1 and T2 time intervals, VB (2.55) and FBF (1.91) were affected by the thermal cycle much more, respectively. But, at T1 time interval, SDR was less affected (1.35) (Table 5).

**DISCUSSION**

The amount of unreacted monomers in the RBCs varies depending on the chemical structure of the RBC, the degree of polymerization of the monomers, the cross-link density in the polymer network, the surface treatments applied to the filler particles, and the features of the solvent. The degree of resolution of the material and the molecular weights of the monomers are the most important factors affecting the chemical structure of the RBCs\(^{21,22}\).

Many solutions have been used to examine the effect of chemical solvents in the oral environment on the RBC. While Sideridou and Achilias\(^{23}\) used ethanol-water mixture in their studies, Stefova et al.\(^{24}\), Uzunova et al.\(^{25}\), and Tanaka et al.\(^{26}\) preferred only water as solvent. Spahl and Budzikiewicz\(^{27}\) used only methanol as solvent. It has been recommended by the US Food and Drug Administration to use 75% ethanol-water solvent as the closest fluid to simulate food and beverages and many researchers have used this mixture in their studies\(^{28-30}\).

In the laboratory conditions, it is commonly preferred thermocycling devices to evaluate the effect of temperature changes on RBCs. In this study, cold and hot baths values were determined as 5 and 55°C, respectively. In order to keep the timing of the thermal cycle group equal to that of the control group, the immersing time of each bath was determined to be 25 s (The time interval between two baths is 7 s). The samples in the control group were kept at 37°C in order to simulate the temperature value of the mouth environment during the test process.

The application of thermocycling increased the amounts of TEGDMA and Bis-EMA monomers, which were released from the VB, more than the other RBCs. In some regions of the polymer network of a RBC, the cross-link density is greater, while in some regions this density is less. In the regions where the polymerization reaction occurs, heterogeneous areas become frequent, especially in cross-linking sites. Unreacted monomers are trapped between polymer chains and monomer ponds are formed. These monomer ponds are more dense in RBCs where the polymer structure is more heterogeneous\(^{31,32}\). The thermocycling process expands and shrinks the polymer networks, then the network is broke up\(^{33}\). Thus, the elution of unreacted monomers between the polymer clusters increase. RBCs which have more heterogeneous areas in the polymer network may be more affected by the thermocycling application. Bis-GMA has rigid BPA core structure. Although the molecular weight of the UDMA is close to that of Bis-GMA, the absence of phenol rings enables a more flexible structure with high hardness compared to Bis-GMA\(^{34}\). More rigid monomers such as Bis-GMA make the polymer network more homogeneous, while more flexible monomers such as UDMA and TEGDMA make the polymer network heterogeneous\(^{35,36}\). In the present study, it was determined that Bis-GMA monomer was found in very low amounts in VB, and UDMA and TEGDMA monomers displayed more abundant. Alshali et al.\(^{37}\) stated that there is no Bis-GMA monomer in VB. In addition to the UDMA monomer, the use of low weight monomers such as TEGDMA will increase the flexibility of the polymer network\(^{38}\). The polymer network that included too much flexible structure is more sensitive to thermal changes. Alshali et al.\(^{37}\) reported that UDMA-Bis-EMA based systems are more tend to elution than Bis-GMA-Bis-EMA. The presence of a polymer network based on UDMA-Bis-EMA and a heterogeneous and flexible structure of the polymer network may have caused the VB to be more affected by thermal changes.

In TB, the thermal changes affected the amount of Bis-GMA monomer lower than other RBCs. The TB has a high filler ratio by weight (77%). In addition, the polymer structure is composed of monomers with higher molecular weight such as Bis-GMA and UDMA. These factors may have provided the TB structure to be less affected by thermal changes\(^{38}\).

Thermocycling increased the amount of released TEGDMA, UDMA and Bis-EMA from SDR lower than other RBCs. The modified UDMA monomer (849 g/mol) used by the manufacturer in SDR has a higher molecular weight than the conventional monomers. Increasing the molecular weight of the UDMA monomer also increased its homeogenicity\(^{39}\). The polymer structure of the SDR is more homogeneous and strong, and it has high filler content, so the effects of thermal changes as shrinkage and expansion can be minimized. Similar to the results of the present study, Czasch and Ilie\(^{39}\) found that the mechanical properties of SDR were higher than that of VB. Increasing the mechanical properties of the RBCs may provide the polymer structure to be less affected by thermal cycling effects\(^{38}\).

Tabatabaei et al.\(^{40}\) and Tokay et al.\(^{41}\) found that the thermocycling increased the amount of monomer released in significant amounts. These findings are in parallel with the results of our study. Also the highest amount of monomer was released within the first 24 h in the present study. Sideridou and Achilias\(^{23}\) reported that the TEGDMA monomer elution was completed in about 3 days. In the present study, it was determined that the TEGDMA monomer, which was released from VB, was completed in 1 day, but which was released from SDR and FZ were completed in 3 days. In the SF, TEGDMA elution was observed for 7 days. Bis-EMA monomers were observed in all time periods in SF and VB, whereas in the other RBCs, the elution was generally completed in the first 24 h. The longer duration of TEGDMA and Bis-EMA monomer release in SF may be due to the fact
that the TEGDMA and Bis-EMA monomer contents in SP are much higher than other RBCs.

In the present study, TEGDMA was more eluted in the first 24 h than the other monomers. Tanaka et al. found that the molecules at the small size release much more compared to the molecules at the large size. Molecules in small size can move faster, so they are released in much shorter time than large molecules. TEGDMA is much smaller than other monomers. In the present study, the faster elution of the TEGDMA is probably due to the its smaller size and its more motion than the other monomers. Bis-EMA monomer is a common name for Bisphenol A based homologous sequences and contains multiple monomers. It is disintegrated in a short time due to its high reactive structure and reveals monomeric structures in small size. Monomers in this small size can also be released in a short time with their ability to move quickly.

CONCLUSION

The null-hypothesis was rejected; The thermocycling increased the monomer elution of the RBCs by a significant amount. RBCs containing higher molecular weight monomers such as Bis-GMA and UDMA can be less affected by thermal cycling. RBCs containing more TEGDMA monomer can be more prone to elution. It can be supposed that this difference is related to the quality of the homogeneity of the polymer network in the RBCs.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

1) Sunnegårdh-Grönberg K, van Dijken JW, Funegård U, Lindberg A, Nilsson M. Selection of dental materials and longevity of replaced restorations in Public Dental Health clinics in northern Sweden. J Dent 2009; 37: 673-678.
2) Yap AU, Pandya M, Toh WS. Depth of cure of contemporary bulk-fill resin-based composites. Dent Mater J 2016; 35: 503-510.
3) Ferracane JL, Condon JR. Rate of elution of leachable components from composite. Dent Mater 1990; 6: 282-287.
4) Müller H, Olsson S, Söderholm KJ. The effect of comonomer composition, silane heating, and filler type on aqueous TEGDMA leachability in model resin composites. Eur J Oral Sci 1997; 105: 362-365.
5) Coelho AJM. Endocrine disruptors and dental materials: health implications associated with their use in Brazil. Cad Saude Publica 2002; 18: 505-509.
6) Olea N, Pulgar R, Pérez P, Olea-Serrano F, Rivas A, Novillo-Fertoll A, et al. Estrogenicity of resin-based composites and sealants used in dentistry. Environ Health Perspect 1996; 104: 298-305.
7) Accorinte MdLR, Loguerio AD, Reis A, Muench A, de Araújo VC. Adverse effects of human pulps after direct pulp capping with the different components from a total-etch, three-step adhesive system. Dent Mater 2005; 21: 599-607.
8) Lee DH, Lim BS, Lee YK, Ahn SJ, Yang HC. Involvement of oxidative stress in mutagenicity and apoptosis caused by dental resin monomers in cell cultures. Dent Mater 2006; 22: 1086-1092.
9) Leprince JG, Palin WM, Hadis MA, Devaux J, Leloup G. Progress in dimethacrylate-based dental composite technology and curing efficiency. Dent Mater 2013; 29: 139-156.
10) Lempel E, Cizbulya Z, Kunsági-Máté S, Szalma J, Sümegi B, Böddi K. Quantification of conversion degree and monomer elution from dental composite using HPLC and micro-Raman spectroscopy. Chromatographia 2014; 77: 1137-1144.
11) Ohici AC, Sinhoreti MAC, Florellini E, Correr-Sobrinho L, De Goes MF, Henriques GEP. Monomer conversion at different dental composite depths using six light-curing methods. Polymer Testing 2006; 25: 282-288.
12) Price RB, Murphy DG, Derand T. Light energy transmission through cured resin composite and human dentin. Quintessence Int 2000; 31: 659-667.
13) Sarrett DC. Clinical challenges and the relevance of materials testing for posterior composite restorations. Dent Mater 2005; 21: 9-20.
14) Göpfich A. Mechanisms of polymer degradation and erosion. Biomaterials 1996; 17: 103-114.
15) Lee SY, Greener EH, Menis DL. Detection of leached moieties from dental composites in fluid simulating food and saliva. Dent Mater 1995; 11: 348-353.
16) Michailosco P, Marciano J, Grieve A, Abadie M. An in vivo recording of variations in oral temperature during meals: a pilot study. J Prosthet Dent 1995; 73: 214-218.
17) Sund-Levander M, Forsberg C, Wahren LK. Normal oral, rectal, tympanic and axillary body temperature in adult men and women: a systematic literature review. Scand J Caring Sci 2002; 16: 122-128.
18) Mair L. Surface permeability and degradation of dental composites resulting from oral temperature changes. Dent Mater 1989; 5: 247-255.
19) Miyazaki M, Sato M, Onose H, Moore BK. Influence of thermal cycling on dentin bond strength of two-step bonding systems. Am J Dent 1998; 11: 118-122.
20) Hashimoto M, Ohizo H, Kaga M, Endo K, Sano H, Oguchi H. In vivo degradation of resin-dentin bonds in humans over 1 to 3 years. J Dent Res 2000; 79: 1385-1391.
21) Santerre J, Shajii L, Leung B. Relation of dental composite formulations to their degradation and the release of hydrolyzed polymeric-resin-derived products. Crit Rev Oral Biol Med 2001; 12: 136-151.
22) Ferracane JL. Hygroscopic and hydrolytic effects in dental polymer networks. Dent Mater 2006; 22: 211-222.
23) Sideridou ID, Achilias DS. Elution study of unreacted Bis-GMA, TEGDMA, UDMA, and Bis-EMA from light-cured dental resins and resin composites using HPLC. J Biomed Mater Res B Appl Biomater 2005; 74: 617-626.
24) Stefova M, Ivanova V, Muratovska I. Identification and quantification of Bis-GMA and Teg-DMA released from dental materials by HPLC. J Liq Chromatogr Rel Technol 2005; 28: 289-295.
25) Uzunova Y, Lukanov L, Filipov I, Vladimirov S. High-performance liquid chromatographic determination of unreacted monomers and other residues contained in dental composites. J Biochem Biophys Methods 2008; 70: 883-888.
26) Tanaka K, Taira M, Shintani H, Wakasa K, Yamaki M. Residual monomers (TEGDMA and Bis-GMA) of a set visible-
light-cured dental composite resin when immersed in water. J Oral Rehabil 1991; 18: 353-362.

27) Spahl W, Budzikiewicz H. Qualitative analysis of dental resin composites by gas and liquid chromatography/mass spectrometry. Fresenius J Anal Chem 1994; 350: 684-691.

28) Polydorou O, Trittler R, Hellwig E, Kummerer K. Elution of monomers from two conventional dental composite materials. Dent Mater 2007; 23: 1535-1541.

29) Cebe MA, Cebe F, Cengiz MF, Cetin AR, Arpag OF, Ozturk B. Elution of monomer from different bulk fill dental composite resins. Dent Mater 2015; 31: e141-e149.

30) FDA U. Recommendations for chemistry data for indirect food additive petitions. US FDA: Washington, DC 1995.

31) Lagocka R, Jakubowska K, Chlubek D, Buczkowska-Radińska J. Elution study of unreacted TEGDMA from bulk-fill composite (SDR Dentsply) using HPLC. Adv Med Sci 2015; 60: 191-198.

32) Lovell LG, Berchtold KA, Elliott JE, Lu H, Bowman CN. Understanding the kinetics and network formation of dimethacrylate dental resins. Polym Adv Technol 2001; 12: 335-345.

33) Gale M, Darvell B. Thermal cycling procedures for laboratory testing of dental restorations. J Dent 1999; 27: 89-99.

34) Alshali RZ, Salim NA, Sung R, Satterthwaite JD, Silikas N. Qualitative and quantitative characterization of monomers of uncured bulk-fill and conventional resin-composites using liquid chromatography/mass spectrometry. Dent Mater 2015; 31: 711-720.

35) Elliott J, Lovell L, Bowman C. Primary cyclization in the polymerization of bis-GMA and TEGDMA: a modeling approach to understanding the cure of dental resins. Dent Mater 2001; 17: 221-229.

36) Achilias DS, Karabela MM, Sideridou ID. Thermal degradation of light-cured dimethacrylate resins: Part I. Isoconversional kinetic analysis. Thermochimica Acta 2008; 472: 74-83.

37) Alshali RZ, Salim NA, Sung R, Satterthwaite JD, Silikas N. Analysis of long-term monomer elution from bulk-fill and conventional resin-composites using high performance liquid chromatography. Dent Mater 2015; 31: 1587-1598.

38) Asmussen E, Peutzfeldt A. Influence of UEDMA, Bis-GMA and TEGDMA on selected mechanical properties of experimental resin composites. Dent Mater 1998; 14: 51-56.

39) Czasch P, Ilie N. In vitro comparison of mechanical properties and degree of cure of bulk fill composites. Clin Oral Investig 2013; 17: 227-235.

40) Tabatabaei MH, Sadrai S, Bassir SH, Veisy N, Dehghan S. Effect of food stimulated liquids and thermocycling on the monomer elution from a nanofilled composite. Open Dent J 2013; 7: 62-67.

41) Tokay U, Koyuturk AE, Aksoy A, Ozmen B. Do the monomers release from the composite resins after artificial aging? Microse Res Tech 2015; 78: 255-259.

42) Örtengren U, Wellendorf H, Karlsson S, Ruyter I. Water sorption and solubility of dental composites and identification of monomers released in an aqueous environment. J Oral Rehabil 2001; 28: 1106-1115.

43) Smith MB, March J. March’s advanced organic chemistry: reactions, mechanisms, and structure: John Wiley & Sons; 2007.