Degree of Conversion and Polymerization Shrinkage of Low Shrinkage Bulk-Fill Resin Composites

Abstract

Background: The effectiveness of each resin composite material composition in enabling homogeneous monomer conversion and reducing polymerization shrinkage (PS) is an important issue. Thus, this study aimed to evaluate the degree of conversion (DC) and PS of low-shrinkage bulk-fill composites (BFCs) in 4-mm thickness. Materials and Methods: Four bulk fill (Tetric EvoCeram Bulk Fill, Sonic Fill, XTra Fill, and Venus Bulk Fill) and one conventional (Filtek Z350 XT) resin composites were tested in this study. Teflon molds of 4-mm depth were used to prepare resin composite specimens. All tested resin composites were packed in bulk then light cured for the recommended time by their manufacturers. DC% was determined by Fourier transform infrared spectroscopy; PS was determined using the strain gauge method. Data were subjected to one-way ANOVA/Tukey’s test (α = 0.05). Results: DC% results were as follows: Venus Bulk Fill > XTra Fill > Sonic Fill > Tetric EvoCeram Bulk Fill > Filtek Z350 XT with a significant difference between each others at P ≤ 0.001. For PS %, significant difference resulted between tested groups at P ≤ 0.001. Where Venus Bulk Fill < Xtra Fill = Sonic Fill < Tetric EvoCeram Bulk Fill < Filtek Z350 XT. Conclusions: Low-shrinkage resin monomers seem to be beneficial for reducing PS with enhancement in the DC. Increased filler loading in BFCs had a positive effect on reducing PS, while its effect on the DC was material dependent.

Keywords: Bulk fill, degree of conversion, resin, shrinkage

Introduction

Dental Resin based composite (RBC) restorations are the most widely demanded restorations in dental practice due to its esthetic properties. In spite of the continuous improvements in resin composite over the last decades, it still suffers from its shrinkage during polymerization and the accompanied stresses plus being a technique sensitive restoration with prolonged application time. The incremental application technique is a common protocol for application of conventional light activated composites, which is done by applying increments no thicker than 2 mm to ensure a homogeneous degree of conversion (DC) throughout the material thickness plus being a way to reduce polymerization stress.[1,2]

Aiming to decrease the clinical application time of resin composite, the so-called “bulk fill” composites (BFCs) were introduced in the market. Manufacturers of BFCs claimed that these materials allow uniform polymerization of increments up to 4–5-mm thickness, with low polymerization shrinkage (PS) than conventional RBCs.[3]

Different attempts were followed by BFCs manufacturers to optimize the polymerization and lower the volumetric PS such as utilizing; stress reliever, polymerization modulator,[4] or by variations in the filler size (Xtra Fill [VOCO]) and filler content (Tetric EvoCeram Bulk Fill [Ivoclar Vivadent]) and change in the chemistry of their resin matrix[1-3] for example; introducing low-shrinkage monomers (e.g., (ethoxylated bisphenol A dimethacrylates monomer [EBPADA]) (Sonic Fill [Kerr], and Venus Bulk Fill [Heraeus Kulzer]).

Results of studies that have been carried out with this new category of materials are contradicting. Some authors found similar or higher DC and lower shrinkage of bulk-fill materials at 4 mm thickness.[4,5] On the other hand, others revealed a significant decrease of conversion in BFCs at 4 mm thickness,[1,6] or higher volumetric shrinkage of low shrinkage bulk-fill resin composites.
shrinkage than that of conventional composites. Thus, the clinical implications of the use of these new materials seem unclear.

Based on this knowledge, the purpose of the present study was to evaluate the DC and PS of different BFCs compared to conventional resin composite, to assess the effectiveness of each manufacturer approach in enabling homogeneous monomer conversion and reducing PS. The null hypothesis was that the different bulk fill and conventional resin composites tested in this study present similar performance in terms of DC, and PS.

Materials and Methods

Selected materials

Five commercial resin composites; one conventional and four bulk-fill resin composite materials were selected for this study. Materials name, manufacturers and their composition, time/irradiance are presented in Table 1.

Degree of conversion test

Specimens preparation for the DC testing:

Fifty specimens were prepared for the the DC test. They were divided into five groups (n = 10/group) representing the tested resin composites. The 10 specimens of each group were divided as follows: five uncured specimens to serve as control and five experimental cured resin composite specimens.

For preparing the 25 experimental cured resin composite specimens (n = 5/group); sectional Teflon molds of 6-mm diameter and 4-mm thickness were used. The molds were first mounted on the top of a microscope slide and a Mylar strip, and then the mold was filled in bulk with one of the tested resin composites using a plastic spatula. Only, Sonic Fill resin composite; was inserted into the molds with a handpiece that produced ultrasonic waves according to the manufacturer’s instructions. The top side of the mold was covered with a second Mylar strip to prevent oxygen inhibition. A glass microscope slide with a load of 1 kg was applied for 30 s to ensure consistent packing of the specimens. The load and the microscope slide were then removed. The specimens were light-cured from the top surface only using LED Elipar S10 light curing unit (Elipar S10, 3M ESPE Dental Products, St. Paul, MN, USA) with an output of >1000 mW/cm² for the recommended time as mentioned by the manufacturer of each tested resin composite [Table 1].

The light curing tip was kept centered and in direct contact with the second Mylar strip. The power density of the light curing unit was assessed using a hand-held radiometer (Curing Radiometer, Demetron, Danbury, CT, USA). After light curing, the cylindrical specimens were pushed out of the mold, and excess resin composite material was removed with a plastic spatula.

Specimens were stored in light-proof containers before the tests were conducted, in complete darkness at 37°C for 24 h to prevent ambient light from causing additional postlight curing polymerization.

Degree of conversion testing

Fourier transform infrared (FT-IR) spectra of the uncured and cured tested resin composite materials were obtained using 24 scans at 4 cm⁻¹ in the absorbance mode (Jasco FT-IR 6400, Japan). The FT-IR spectroscopy was completed using a potassium bromide pellet technique.

Twenty-five uncured specimens (n = 5/group) were prepared for FT-IR testing to be used as control specimens for the five resin composites tested in this study.

For preparation of the control specimens; 2 mg of each of the uncured resin composites were blended with 7 mg of Ispectropic grade (IR) potassium bromide powder in a specimen holder; then it was pressed into a transparent disc (1-mm thickness) under heavy pressure for 1 min, using a pellet maker kit (KBr Product-A-Press, International Crystal Labs, Garfield, NJ, USA), before it was subjected to FT-IR analysis.

For the previously prepared experimental cured resin composite specimens; FT-IR spectra were obtained

| Composite type       | Material/manufacturer                       | Organic matrix | Filler content | Tim/irradiance |
|----------------------|---------------------------------------------|----------------|---------------|----------------|
| Conventional composites | Filtek Z350 XT/3M ESPE, St Paul, USA       | Bis-GMA, Bis-EMA, UDMA, TEGDMA | 72.5 wt%       | 20-s/(>1000 mW/cm²) |
| Bulk-fill composites | Tetric EvoCeram Bulk Fill/Ivoclar Vivadent AG, Schaan, Liechtenstein, Germany | Bis-GMA, Bis-EMA, UDMA | 79 wt%-81 wt% | 10-s/(>1000 mW/cm²) |
|                      | Sonic Fill/Kerr Corporation, Orange, California, USA | Bis-GMA, TEGDMA, EBPADMA | 83.5 wt% | 20-sec/(>1000 mW/cm²) |
|                      | XTra Fill/VOCO, Cuxhaven, Germany            | Bis-GMA, UDMA, TEGDMA | 86 wt% | 10-s/(>1000 mW/cm²) |
|                      | Venus Bulk Fill/Heraeus Kulzer GmbH, Hanau, Germany | EBPADMA, UDMA | 70.1 vol% | 20-s/(>1000 mW/cm²) |
|                      |                                              |                | 65 wt%, 38 vol% |               |

Bis-GMA: Bisphenol-glycidyl methacrylate; Bis-EMA: Ethoxylated methacrylate; UDMA: Urethane dimethacrylate; TEGDMA: Triethylene glycol dimethacrylate; EBPADMA: Ethoxylated bisphenol A dimethacrylates
after 24 h in dark storage at 37°C. Each specimen was completely crushed and ground into fine powder using a mortar and a pestle. Subsequently, 2 mg of each resin composite powder was blended with 7 mg of IR potassium bromide in a specimen holder, and then it was pressed into a transparent disc using a pellet maker kit. The specimen holder was transferred to the spectrometer, and a spectrum was obtained using the same parameters as for the uncured resin composites specimens.

For calculating the DC%, the percentage of unreacted carbon-carbon double bonds (%C = C) was determined from the ratio of absorbance peak areas of aliphatic carbon-carbon double bonds C = C (peak at 1638 cm⁻¹) against aromatic component (peak at 1608 cm⁻¹) which was used as an internal standard before and after curing. The underlying peak area was calculated for each peak, using a standard baseline technique with the aid of a computer software program provided with the spectrometer (Spectra Manager Version 2). The DC was determined according to the formula in Figure 1.

### Polymerization shrinkage test

A total of 50 specimens were prepared for the polymerization volumetric shrinkage test. Specimens were divided into five groups (n = 10/group) representing the tested resin composites.

The test setup included a white Teflon frame 4-mm diameter and 4-mm height that was used to circumscribe the resin composite specimens. The Teflon frame was chosen so as not to adhere to the resin composite, thus allowing its free shrinkage. A glass slide served as a base for the setup. A foil electrical resistance strain gauge (Strain Gauges, Kyowa Electronic Instruments Co, LTD, Tokyo, Japan, Lot #Y4003S) was placed onto the flat glass surface at the center of the mold. The gauge was 1 mm in length and had an electric resistance of 120Ω and a gauge factor of 2.09% ± 1.0%.[6,8]

Resin composite restorative material was placed in the cavity of the Teflon frame in a single increment using a plastic spatula, with the strain gauge centralized in place. Only, Sonic Fill resin composite; was inserted into the molds with a handpiece that produced ultrasonic waves according to the manufacturer’s instructions. Care was taken to ensure complete filling of the frame followed by placement of a Mylar polyester strip; then, the excess composite material was extruded using pressure applied through a second glass slide that was then removed. The foil strain gauge was connected to a strain-monitoring device (Strain-Meter PCD-300A Kyowa-Electronic Instruments Co, LTD, Tokyo, Japan) initially balanced at zero. The resin composite was cured using LED curing unit (Elipar S10, 3M ESPE Dental Products, St. Paul, MN, USA) with an output of >1000 mW/cm² for the recommended time of each material by the manufacturers [Table 1]. Strain measurements were recorded during curing and 5 min following light irradiation at room temperature (25°C ± 1°C).[5,8]

### Statistical analysis

Data presented as the mean and standard deviation (SD). Data explored from normality using Kolmogorov–Smirnov and Shapiro–Wilk tests. Data showed a parametric distribution, so one-way ANOVA was used to study the effect of different materials followed by Tukey’s honest significant difference post hoc test for pairwise comparison. The significance level was set at P ≤ 0.05. Statistical analysis was performed with IBM® SPSS® (SPSS Inc., IBM Corporation, NY, USA) version 25 for windows.

### Results

Table 2 shows the results of the DC percentage (DC %) and PS%.

DC % overlapped with line chart showing the PS% for different tested materials is presented in Figure 2.

### Discussion

The setting process of resin composite has a major effect on its mechanical and biological properties. Filler loading, shape and size, resin matrix composition, photoinitiator concentration, and the polymerization conditions are all factors influencing resin polymerization. Since polymerization conditions, such as layer thickness, intensity of the curing unit and exposure times (according to each manufacturer instruction), were standardized in this study, differences in the DC value of conventional and bulk-fill RBCs could be explained by the different composition of the materials, mainly to difference in the chemistry of their resin matrix and the filler loading.

### Table 2: One-way ANOVA results for degree of conversion% and polymerization shrinkage (s%) Mean±SD

|               | Filtek Z350 XT | Tetric EvoCeram Bulk Fill | SonicFill | Xtra Fill | Venus Bulk Fill | P     |
|---------------|----------------|--------------------------|-----------|-----------|----------------|-------|
| Degree of conversion (%) | 14.76±0.05    | 41.06±0.09               | 63.04±0.05| 64.20±0.07| 86.10±0.12     | ≤0.001*|
| Polymerization shrinkage (%) | 2.12±0.08    | 1.95±0.03                | 1.24±0.05 | 1.17±0.09 | 0.39±0.02      | ≤0.001*|

Same letter within each row is not significant. *Significant. SD: Standard deviation.

1. Degree of conversion formula

Figure 1: Degree of conversion formula

% DC = 1- (aliphatic C=C/aromatic C=C) of polymer x 100
(aliphatic C=C/aromatic C=C) of monomer

### References

[5,8] Since
Results of this study revealed that the conventional resin composite Filtek Z350 XT showed the least DC% compared to all tested bulk-fill resin composites. These results were expected as the conventional resin composite was placed in bulk and tested at 4-mm thickness, while it is recommended by its manufacturer to be placed in increments not >2 mm thickness to ensure homogeneous DC throughout the material thickness plus being a way to reduce polymerization stress.\[1\]

It seems that BFCs manufacturers had followed different strategies to increase the depth of cure in these resin composites, which in turn affect the degree of monomer conversion into the polymer which can explain the high DC at 4 mm observed for bulk-fill materials when compared to conventional composites.

The Venus Bulk-Fill resin, revealed the highest DC, compared to all tested bulk-fill materials at this study at 4-mm thickness. This could be explained by its high translucency\[14\] and lower filler content\[9\] leading to more light transmission and constant conversion from the top to the 4-mm depth. Moreover, the chemical compositions of the resin matrices play an important role in the DC of this bulk-fill resin composite. The initial viscosity and the flexibility of the monomers crystalline structure are the main features affecting the DC.\[12\]

Venus BFCs have a large amount of UDMA and EBPADMA, which are low viscous monomers that allow the prolonging of the polymerization reaction so increase the degree of monomer conversion.\[15\] Our results are in agreement with other studies that found the higher conversion of Venus Bulk Fill compared to other bulk-fill resin composites both in superficial layers and at 4-mm depth.\[5,14\]

For XTrA Fill resin composite, the manufacturer increased the filler size. Consequently, the specific surface between fillers and the organic matrix is lowered, thus reducing light scattering.\[3\] XTrA Fill has high translucency despite its high filler loading, which is related to the increase filler size as mentioned before and by the improved refractive indices of the filler particles and the resin matrix.\[15\]

On the other hand, Sonic Fill (sonic activated bulk-fill system) contains special modifiers of photoinitiators and uses refractive index matching in the composite material, aiming to increase the depth of cure and the DC in depth up to 5 mm.

Sonic fill revealed a significant decrease in the DC compared to (Venus Bulk Fill and XTrA Fill resin). This might be due to that it has low translucency which was confirmed by previous studies compared to other bulk-fill materials.\[16,17\] Low translucency affects the light transmission with negative effect on the depth of conversion.\[18\]

The superiority of Venus Bulk Fill, Xtra Fill and Sonic Fill compared to Tetric EvoCeram bulk-fill regarding DC% was related to their resin matrix composition which contains low viscosity monomers TEGDMA, UDMA (Xtra Fill and Venus Bulk Fill), and EBPADMA (Venus Bulk fill and Sonic Fill) these low viscous monomers increased the flow and decreased the viscosity of the resin matrix and thus increasing DC%, as these monomers are more flexible and flowable monomers than Bis-GMA and Bis-EMA present in Tetric EvoCeram Bulk Fill.\[19\]

The manufacturer of Tetric EvoCeram Bulk Fill added an additional photo-initiator (Ivocerin) in the resin composite formula, aiming to act as a polymerization booster offering greater reactivity to curing light compared to camphorquinone at depth up to 4 mm. Despite this, it revealed the least DC compared to the other tested bulk-fill resin composites. Tetric EvoCeram Bulk Fill is a nanohybrid composite contains high nano-filler plus prepolymerized resin fillers loading.\[2\] Prepolymerized fillers are fillers embedded in resin, polymerized and milled to obtain the desired particle size. It is well known that light intensity decreases as it passes through the material. Both intensity of the light source and attenuating power of the material influence the DC.\[14\] Prepolymerized fillers, plus the high filler loading (79–81 wt%) of Tetric EvoCeram Bulk Fill might strongly influence the intensity of the incident light, limiting the depth of cure.

On the contrary, a study performed by Alrahlah et al.\[19\] found that Sonic Fill and Tetric EvoCeram Bulk Fill showed greater depth of cure than Venus Bulk Fill at a depth of 4 mm. This conflict might be due to the different methodologies applied. In Alrahlah et al.,\[19\] the methodology was based on an evaluation of micro-hardness to indirectly determine the DC, and it is not necessarily for a material with the highest micro-hardness to provide the highest DC.

On the other hand, the results of the PS were very interesting as it was unexpected. Although Filtek Z350 XT revealed the lowest DC, it presented a high volumetric
PS, whereas Venus Bulk Fill showed the highest degrees of conversion, but it had the lowest volumetric PS. It is well known and commonly reported in the literature, that monomer conversion is directly proportional to volumetric shrinkage.[20]

For the conventional resin composite Filtek Z350 XT, the high concentration of double bonds of TEGDMA, used as a diluent monomer, may have increased its shrinkage. Greater volumetric shrinkage of the Filtek Z350 XT composite compared to several BFCs was observed by Kim et al.[21] Moveover, all tested bulk-fill resins in this study presented lower shrinkage than the conventional Filtek Z350 XT, which was in agreement with other studies.[21,22]

Many factors affect the volumetric PS of resin composite. The filler content, flow and rate of the modulus of the resin are the major factors.[23] The least shrinkage was presented for Venus bulk fill, this was inconsistent with the studies of Lee[24] and Rosatto et al.[25] which showed that the consistency of the composite is a crucial aspect for determining the axial shrinkage. The low shrinkage of Venus bulk fill could be explained by its very low viscoelastic properties in comparison to the other tested composites[26] that would increase the radial shrinkage and subsequently reduce the axial shrinkage.

Moreover, Venus Bulk Fill resin matrix is based on the low-shrinkage (EBPADMA), which are more hydrophobic analogs of Bis-GMA, and reportedly exhibit higher DC and lower PS than the standard Bis-GMA/TEGDMA resin systems.[22] These characteristics are mainly related to the more flexible structure, lower viscosity, higher molecular mass, and lower content of diluent monomer needed for EBPADMA, compared to Bis-GMA monomer.[22]

Results of our study revealed that both Xtra Fill and Sonic Fill followed Venus Bulk Fill in the PS percent with insignificant difference between them. This might be related to the high filler content of Xtra Fill (86wt%), thus reducing the amount of organic matrix so in turn reducing shrinkage.[22] On the other hand, reduced PS mechanism in Sonic Fill system was related to its low-shrinkage (EBPADMA) resin polymers properties and its high filler content (83.5%). Moreover, the sonic energy application leads to activation of rheological modifiers in the material’s matrix, which drop the material viscosity up to 87%. This drop in the viscosity increases particle mobility in the early stages of polymerization. This increased mobility delays gelation of the material and also enables greater stress relief via internal flow before gelation.[6,27]

Although Tetric EvoCeram Bulk Fill resin composite revealed the highest PS compared to the other tested bulk-fill materials, it showed lower shrinkage than the conventional resin composite. This could be explained due to its prepolymerized filler particles functionalized with silane, that seems to have relatively low elastic modulus (~110 GPa), causing it to act like a microscopic spring, attenuating the forces of shrinkage stress.[2]

Conclusions
Under the limitations of this in vitro study, the following conclusions could be made:

• Utilizing low-shrinkage resin monomers (e.g., EBPADMA) in bulk-fill resin composites seem to be beneficial for reducing polymerization volumetric shrinkage with enhancement in the DC.

• Increased filler loading in BFCs had a positive effect on reducing polymerization volumetric shrinkage, while its effect on the DC was material dependent.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

References
1. Gonçalves F, Campos LMP, Rodrigues-Júnior EC, Costa FV, Marques PA, Franci CE, et al. A comparative study of bulk-fill composites: Degree of conversion, post-gel shrinkage and cytotoxicity. Braz Oral Res 2018;32:e17.
2. Nagi SM, Moharam LM, Zaazou MH. Effect of resin thickness, and curing time on the micro-hardness of bulk-fill resin composites. J Clin Exp Dent 2015;7:e600-4.
3. Hirata R, Clozza E, Giannini M, Farrokhmanesh E, Janal M, Tovar N, et al. Shrinkage assessment of low shrinkage composites using micro-computed tomography. J Biomed Mater Res B Appl Biomater 2015;103:798-806.
4. Tsujimoto A, Barkmeier WW, Takamizawa T, Latta MA, Miyazaki M. Mechanical properties, volumetric shrinkage and depth of cure of short fiber-reinforced resin composite. Dent Mater J 2016;35:418-24.
5. Par M, Gamulin O, Marovic D, Klaric E, Tarle Z. Raman spectroscopic assessment of degree of conversion of bulk-fill resin composites – Changes at 24 hours post cure. Oper Dent 2015;40:E92-101.
6. Benetti AR, Havndrup-Pedersen C, Honoré D, Pedersen MK, Pallesen U. Bulk-fill resin composites: Polymerization contraction, depth of cure, and gap formation. Oper Dent 2015;40:190-200.
7. Son SA, Park JK, Seo DG, Ko CC, Kwon YH. How light attenuation and filler content affect the microhardness and polymerization shrinkage and translucency of bulk-fill composites? Clin Oral Investig 2017;21:559-65.
8. El-Korashy DI. Post-gel shrinkage strain and degree of conversion of preheated resin composite cured using different regimens. Oper Dent 2010;35:172-9.
9. Cramer NB, Stansbury JW, Bowman CN. Recent advances and developments in composite dental restorative materials. J Dent Res 2011;90:402-16.
10. Leprince JG, Palin WM, Hadis MA, Devaux J, Leloup G. Progress in dimethacrylate-based dental composite technology and curing efficiency. Dent Mater 2013;29:139-56.
11. Kim EH, Jung KH, Son SA, Hur B, Kwon YH, Park JK, et al. Effect of resin thickness on the microhardness and optical...
properties of bulk-fill resin composites. Restor Dent Endod 2015;40:128-35.

12. Miletić V, Pongprueksa P, De Munck J, Brooks NR, Van Meerbeek B. Curing characteristics of flowable and sculptable bulk-fill composites. Clin Oral Investig 2017;21:1201-12.

13. Alshali RZ, Silikas N, Satterthwaite JD. Degree of conversion of bulk-fill compared to conventional resin-composites at two time intervals. Dent Mater 2013;29:e213-7.

14. Zorzin J, Maier E, Harre S, Fey T, Belli R, Lohbauer U, et al. Bulk-fill resin composites: Polymerization properties and extended light curing. Dent Mater 2015;31:293-301.

15. Primus CM, Chu CC, Shelby JE, Buldrini E, Heckle CE. Opalescence of dental porcelain enamels. Quintessence Int 2002;33:439-49.

16. Roggendorf MJ, Krämer N, Appelt A, Naumann M, Frankenberger R. Marginal quality of flowable 4-mm base vs. Conventionally layered resin composite. J Dent 2011;39:643-7.

17. Ilie N, Hickel R. Investigations on mechanical behaviour of dental composites. Clin Oral Investig 2009;13:427-38.

18. Howard B, Wilson ND, Newman SM, Pfeifer CS, Stansbury JW. Relationships between conversion, temperature and optical properties during composite photopolymerization. Acta Biomater 2010;6:2053-9.

19. Alrahlah A, Silikas N, Watts DC. Post-cure depth of cure of bulk fill dental resin-composites. Dent Mater 2014;30:149-54.

20. Kaisarly D, Gezawi ME. Polymerization shrinkage assessment of dental resin composites: A literature review. Odontolgy 2016;104:257-70.

21. Kim RJ, Kim YJ, Choi NS, Lee IB. Polymerization shrinkage, modulus, and shrinkage stress related to tooth-restoration interfacial debonding in bulk-fill composites. J Dent 2015;43:430-9.

22. Jang JH, Park SH, Hwang IN. Polymerization shrinkage and depth of cure of bulk-fill resin composites and highly filled flowable resin. Oper Dent 2015;40:172-80.

23. Chung KH, Greener EH. Correlation between degree of conversion, filler concentration and mechanical properties of posterior composite resins. J Oral Rehabil 1990;17:487-94.

24. Lee YK. Influence of filler on the difference between the transmitted and reflected colors of experimental resin composites. Dent Mater 2008;24:1243-7.

25. Rosatto CM, Bicalho AA, Verissimo C, Bragança GF, Rodrigues MP, Tantbirojn D, et al. Mechanical properties, shrinkage stress, cuspal strain and fracture resistance of molars restored with bulk-fill composites and incremental filling technique. J Dent 2015;43:1519-28.

26. Papadogiannis D, Tolidis K, Gerasimou P, Lakes R, Papadogiannis Y. Viscoelastic properties, creep behavior and degree of conversion of bulk fill composite resins. Dent Mater 2015;31:1533-41.

27. Tiba A, Zeller GG, Estrich CG, Hong A. A laboratory evaluation of bulk-fill versus traditional multi-increment-fill resin-based composites. J Am Dent Assoc 2013;144:1182-3.