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A comparative study of bulk-fill composites: degree of conversion, post-gel shrinkage and cytotoxicity

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Abstract: Bulk-fill composites are claimed to be restorative materials used in deep preparations and effectively photoactivated in layers up to 4 mm. The aim of the present study was to evaluate the degree of conversion, post-gel volumetric shrinkage, and cytotoxicity of six bulk-fill and two conventional composites. Degree of conversion was determined by FTIR spectroscopy; post-gel volumetric shrinkage was determined using the strain gauge method; and cytotoxicity in human fibroblasts was evaluated indirectly by the MTT assay. Data were subjected to one-way ANOVA/Tukey's test (α = 0.05). All materials, including bulk-fill and conventional composites, were classified as non-toxic, with cell viability higher than 70%. Bulk-fill composites exhibited volumetric shrinkage similar to or lower (1.4 to 0.4%) than that of conventional composites (1.7–2.1%). However, only four of the bulk-fill composites were able to sustain a homogeneous conversion at the 4-mm depth. Despite their non-toxicity and shrinkage similar to that of conventional materials, not all commercial bulk-fill materials were able to maintain a conversion as high as 80% of the superficial layer, at the 4-mm depth, indicating some failure in the bulk-fill design of some commercial brands. Therefore, the use of bulk-fill materials in dental practice is advantageous, but special attention should be given to the selection and correct use of the materials.

Keywords: Composite Resins; Materials Testing; Biocompatible Materials.

Introduction

Composites have been extensively studied and improved over the past decades.[1] Nowadays, composites are the material of choice for direct restorations on posterior and anterior teeth, due mainly to their esthetic properties, appropriate mechanical properties, and low cytotoxicity.[1,2] But these materials still have substantial limitations (*e.g.*, polymerization shrinkage[3]), which may cause stress and jeopardize the integrity of the tooth/restoration interface.[4] Several alternatives have been proposed in the literature to reduce polymerization stress, such as the use of low-modulus liners,[5] alternative photoactivation methods like pulse-delay or low irradiance,[6] and the use of incremental filling techniques,[7] which has been completely incorporated into clinical practice.

The use of incremental filling is recommended for conventional light-activated composites, with the insertion and photoactivation of increments no thicker than 2 mm[8]. This protocol is used for two main reasons. First, as a way to reduce polymerization stress; and second, to guarantee a homogeneous degree of conversion throughout the material thickness.[9] However, this protocol demands more time from the dentist to finish a single restoration.

Aiming to reduce the time of the procedure without diminishing the longevity of the restoration materials, the so-called "bulk-fill" composites were launched in the market having the commercial appeal of lowering polymerization shrinkage and dismissing the incremental technique. According to manufacturers, these materials help reduce the clinical time of the restorative procedure, as they allow uniform polymerization of increments up to 4 to 5 mm thickness.[2] This increased polymerization depth is achieved by employing different strategies. For example, modifications in the initiator system by addition of photoinitiators other than camphorquinone;[10] and increased translucency due to filler size, concentration, and refractive index.[11]

Studies have been carried out with this new class of materials; however, the results reported in the literature vary considerably; whereas some authors show similar or higher degree of conversion, lower shrinkage,[12,13], and no cytotoxic effects of bulk-fill materials[2] after comparing the top and the 4 mm bottom,[14,15] others describe a significant decrease of conversion in bulk-fill composites at 4-mm thickness,[2,16] or higher volumetric shrinkage[17,18] than that of conventional hybrid composites, warning against the toxic effect of some bulk-fill materials.[19] Thus, the clinical implications of the use of these new materials seem unclear. Therefore, this study aimed to evaluate six bulk-fill composites and two conventional composites regarding degree of conversion, volumetric shrinkage, and cytotoxicity, in order to assess the effectiveness of bulk-fill resins in enabling homogeneous monomer conversion at the 4-mm thickness of the photoactivated material, ensuring low volumetric shrinkage and proper biological compatibility. The null hypothesis was that composites (bulk-fill and conventional) present similar performance in terms of degree of conversion, cytotoxicity, and shrinkage. Those tests were chosen because if the material presents high conversion, low shrinkage, and low cytotoxicity, it could be safely used by the clinician.

Table 1. Composition, application, and approach for bulk-fill composites.

Composite type	Material (abbreviation) / Manufacturer	Organic matrix*	Filler content*	Application*	Aprroach for bulk-filling
Conventional composites	Filtek Z350 XT (Z350) / 3M ESPE	Bis-GMA, Bis-EMA, UDMA, TEGDMA	72.5 wt%, 66.3 vol%	2 mm thick increments/ oblique technique	-
	Filtek Z350 XT flowable (ZF) / 3M ESPE	Bis-GMA, Bis-EMA, TEGDMA	65 wt%, 46 vol%	2 mm thick increments/ oblique technique	-
Bulk-fill composites	Aura Bulk Fill (AB) / SDI	not available	not available	not available	not available
	everX Posterior (EP)/ GC Europe	Bis-GMA, TEGDMA, PMMA	74.2 wt%, 53.6 vol%	4 mm thick increments/ capping layer required	short E-glass fiber fillers as reinforcement(30) and interpenetrating polymer network , Increased translucency (21)
	SonicFill (SF) / Kerr	Bis-GMA, TEGDMA, EBPADMA	83.5 wt%, 69 vol%	5 mm thick increments/ no capping layer required	rheological modulators and sonic activation*
	Filtek Bulk Fill Posterior (FBP) / 3M ESPE	AUDMA, UDMA, 1,12-dodecane-DMA	76.5 wt% 58.4 vol%	5 mm thick increments/ no capping layer required	High molecular monomers and low elastic modulus*
	Filtek Bulk Fill Flow (FBF) / 3M ESPE	Bis-GMA, Bis-EMA, UDMA, ProAcrylatresins	64.5 wt% 42.5 vol%	4 mm thick increments/ capping layer required	-
	Venus Bulk Fill Flow (VB) / Heraeus Kulzer	UDMA, EBPADMA	65 wt%, 38 vol%	4 mm thick increments/ capping layer required	Increased translucency (22)

Methodology

Eight commercial composites were tested – six bulk-fill materials, one conventional material of regular consistency, and one conventional flowable material (Table 1). Regarding the bulk-fill materials, two showed regular consistency and four were flowable materials. The SonicFill (SF) material was inserted into the cavity with a handpiece that produced ultrasonic waves which, according the manufacturer, sonically activates the material and decreases its viscosity at the insertion time. All the materials were tested with the A2 color. In all the experiments, the specimens were photoactivated using a LED-curing unit (Radii, SDI, Bayswater, Australia) with irradiance of 800 mW/cm² for 25 s, totaling 20 J/cm², which is similar to or higher than the time recommended by the manufacturer.

Degree of conversion

Four metal rings measuring 5 mm in diameter and 1 mm in height were stacked atop one another to simulate a 4-mm-deep cavity. Each of the molds were filled with composite and covered with a polyester strip. The set was photoactivated from the top ring, as described earlier. The presence of the polyester matrix allowed separating the rings after curing and analyzing the degree of conversion at thicknesses of 1, 2, 3, and 4 mm. Irradiance was measured with and without the polyester matrix. The use of polyester matrix did not decrease irradiance.

The degree of conversion was analyzed using Fourier transform infrared spectroscopy (Vertex 70, BrukerOptik GmbH, Germany). The spectra were obtained with a resolution of 4 cm^{-1}, first from the unpolymerized material and 10 min after photoactivation, in increments of 1, 2, 3 and 4 mm (n=5). In the spectrum, the area under the 6165 cm^{-1} absorption peak, corresponding to the =C-H stretch of methacrylate groups, was used to calculate the conversion of the material according to the formula:

Volumetric shrinkage

Post-gel shrinkage was determined using the strain gauge method. A small amount of composite was shaped into a hemisphere (with a radius of 3 mm and height of 1 mm) and placed on the top of a strain gauge (PA-06-060BA-350-LEN, Excel Sensores Ind. Com. e Exportação Ltda., São Paulo, Brazil) and light-cured, as previously described. Microstrain resulting from the polymerization shrinkage was monitored for 5 min and recorded in percentage values. Given that the materials are homogeneous and isotropic on a large scale, the microstrain was multiplied by 3 to represent volumetric shrinkage. The maximum shrinkage value was recorded (n = 5).

Cytotoxicity assay

The current investigation was approved by the Research Ethics Committee of Ibirapuera University (CAAE no. 69202417.0.0000.5597). Human fibroblasts were isolated from keratinized gingival fragments after signature of an informed consent form by the patients. Specimens with 5 mm of diameter and 4 mm of height (n = 3) were built for each composite using the bulk technique and then photoactivated for 25 s. Each specimen was immersed in 1.2 mL of Dubbeco's Modified Eagle Medium (DMEM), supplemented with 10% of fetal bovine serum, and the extracts were collected 24 h after storage according to ISO 10993-5.[20]

Fibroblasts were added in 96-well plates at a concentration of 10,000 cells/well. After 24 h, the culture medium was removed and the extracts from each material were added in the cell culture and maintained therein for 24 h. The cells were washed twice with PBS, and 200 μL of a solution composed of 80% DMEM and 20% 3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) in PBS at 5 mg/mL^{-1} was added. After 3 h in an oven at 37°C, the solution was removed and the formed crystals were diluted in dimethyl sulfoxide. Absorbance was measured at 560 nm in a spectrophotometer (Biotek). Fibroblasts from the fresh culture medium, without any extracts, were used as negative control of cytotoxicity, whereas the culture medium supplemented with 20% of methanol was used as positive control. Cell viability was expressed as the percentage relative to the amount of viable cells in the negative control. According to ISO 10993-5,[20] the material has a cytotoxic potential if cell viability is lower than 70%.

Statistical analysis

The statistical analysis was performed using the Minitab statistical software (Minitab Inc., Pennsylvania, USA). The data were normal and homoskedastic for all experiments. Two-way ANOVA/Tukey's test was performed to evaluate degree of conversion data (factors: material and depth). One-way ANOVA/Tukey's test was performed to analyze volumetric shrinkage and cytotoxicity data. A 95% level of significance was adopted ($\alpha = 0.05$) for all tests.

Results

Degree of conversion

Table 2 shows the degree of conversion of the tested composites as a function of thickness. Note that only composites VB, FBP, and FBF were able to maintain similar conversion at the bottom of the four layers analyzed. Conventional composite Z350 and FBF showed the lowest degree of conversion at the bottom of the first three layers, and Z350 showed the lowest overall conversion at the bottom of the last layer. VB, EP, and SF showed higher conversion at the first 3 mm and VB showed the best conversion for all materials at 4 mm.

$$DC = \left(1 - \frac{\text{Cured}}{\text{Uncured}}\right) \times 100$$

Volumetric shrinkage

The post-gel volumetric shrinkage data are presented in Table 2. VB showed the lowest shrinkage and composite resins Z350, ZF, and FBF showed the highest values.

Cytotoxicity assay

Figure shows cell viability (%) of all materials when photoactivated at a thickness of 4 mm. All materials were considered non-toxic, with cell viability higher than 70%, according to the MTT assay for gingival fibroblasts. Composite resins SF and AB presented cell viability higher than 90%. All other materials showed cell viability between 70 and 89%. Statistically, SF was the lowest cytotoxic material, with cell viability of 99.6 ± 2.7%, and ZF was the most cytotoxic one, with cell viability of 72.1 ± 4.2%.

Discussion

The hypothesis of the study was partially accepted, since not all six bulk-fill composites were able to maintain their conversion at the 4-mm depth. Among the six bulk-fill flowable materials, the performance of two – EverX Posterior (EP) and Sonic Fill (SF) – could be improved by other new technologies, unlike the other materials, composed of short glass fibers as filler reinforcement, and SF, inserted into the cavity with a handpiece that produced ultrasonic waves

Table 2. Degree of conversion (%) of studied composites at different depths.

Composite	Degree of Conversion (%)					Volumetric shrinkage (%)
	Thickness				Bottom/top ratio	
	1 mm	2 mm	3 mm	4 mm		
Filtek Z350XT	52.3 ± 8.6 ^{Da}	53.0 ± 11.7 ^{Ca}	49.3 ± 10 ^{Da}	14.8 ± 3.4 ^{Db}	0.28	2.1 ± 0.6 ^{A}
Filtek Z350XT flow	65.0 ± 5.5 ^{BCa}	59.1 ± 4.5 ^{BCa}	55.6 ± 5.6 ^{CDa}	38.7 ± 8.6 ^{Cb}	0.60	1.7 ± 0.3 ^{AB}
Aura SDI bulk fill	61.9 ± 6.6 ^{CDa}	59.2 ± 6.7 ^{BCab}	58.9 ± 4.5 ^{BCDab}	48.1 ± 7.9 ^{Cb}	0.78	1.3 ± 0.2 ^{BC}
EverX posterior	72.8 ± 0.7 ^{ABCab}	77.6 ± 3.5 ^{Aa}	76.0 ± 0.9 ^{Aba}	68.2 ± 2.8 ^{Bb}	0.94	0.7 ± 0.1 ^{CD}
Filtek bulk fill	74.3 ± 5.2 ^{ABa}	70.6 ± 9.3 ^{ABa}	67.0 ± 9.3 ^{BCa}	64.2 ± 7.4 ^{Ba}	0.86	1.1 ± 0.1 ^{BC}
Filtek bulk fill flow	51.1 ± 7.3 ^{Da}	50.8 ± 3.6 ^{Ca}	43.4 ± 5.7 ^{Da}	41.0 ± 2.5 ^{Ca}	0.80	1.4 ± 0.2 ^{AB}
SonicFill	85.0 ± 2.8 ^{Aa}	77.2 ± 4.4 ^{Ab}	74.6 ± 2.5 ^{ABb}	63.0 ± 5.0 ^{Bc}	0.74	1.2 ± 0.3 ^{BC}
Venus bulk fill flow	85.9 ± 3.3 ^{Aa}	83.2 ± 8.4 ^{Aa}	84.9 ± 9.8 ^{Aa}	86.0 ± 5.7 ^{Aa}	1.0	0.4 ± 0.1 ^{D}

Volumetric shrinkage (%) of studied composites. Same letters indicate statistically similar results ($p > 0.05$). Same capital letters for columns and same lower-case letters for rows indicate statistically similar results.

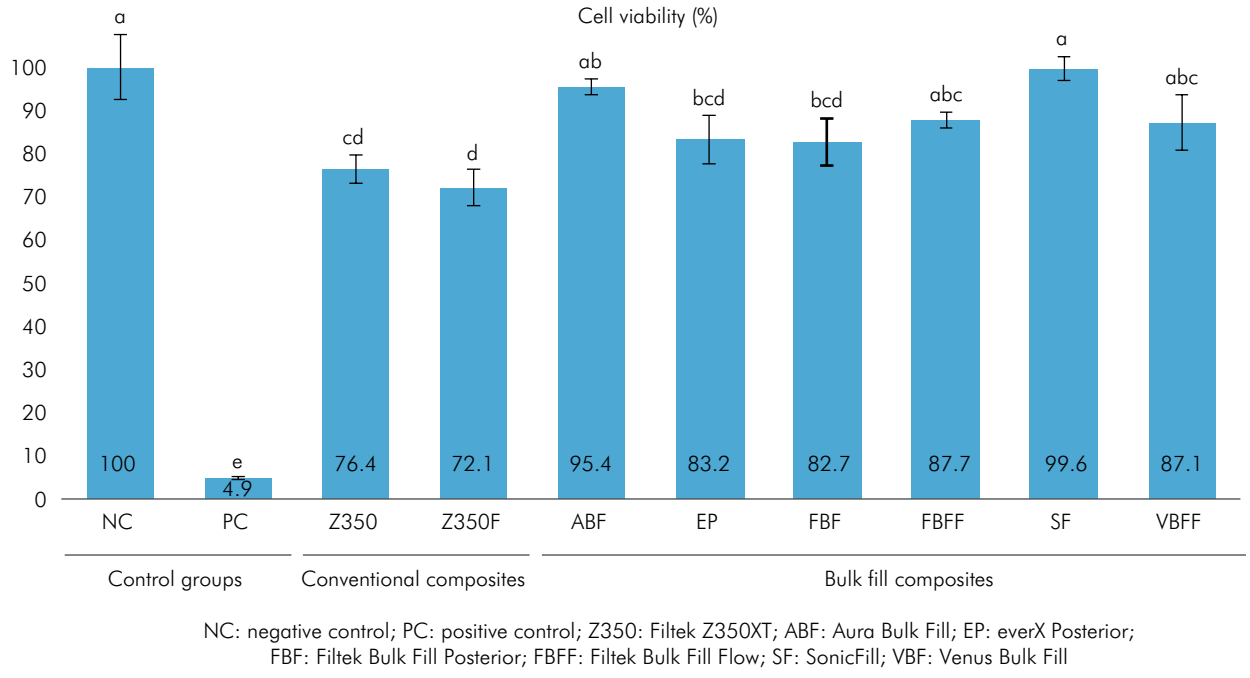

Figure. Cell viability (%) of studied composites. Same letters indicate statistically similar results ($p > 0.05$).

which, according to the manufacturer, sonically activate the material and decrease its viscosity at the insertion time. Both characteristics may have affected the observed outcomes. Regarding the degree of conversion, only three (VB, FBP, and FBF) of the six bulk-fill resins evaluated were able to maintain statistically similar values of conversion at 4 mm and four (VB, FBP, FBF, and EP) were able to maintain up to 80% of their conversion at the bottom when compared to the top surface. Despite the statistical difference among the layers, all bulk-fill materials, except for Aura, showed a high level of conversion (greater than 60%) at 4 mm, and these values were numerically similar (if compared to conventional flow composites) or higher (if compared to conventional regular composites) than the first layer of conventional composites, which would unlikely result in clinical differences in performance. Furthermore, all bulk-fill materials were able to maintain a high and consistent degree of conversion up to 3 mm.

These data are consistent with those of other studies, in which conversion at the 4-mm thickness was maintained for some of these materials.[15,16,21] As the Aura bulk-fill material is relatively new on the market, there are no studies about its conversion with which we could compare our data. Some studies have shown that bulk-fill composites, except for Sonic Fill, are more translucent than conventional composites,[22,23,24] due to filler size, concentration, and refractive index. This can explain the high conversion at 4 mm observed for bulk fill materials when compared to conventional composites. For SF, however, there was a decrease in the degree of conversion from the top to the depth of 4 mm; in fact, unlike most bulk-fill composites, it presents low translucency, when compared to conventional composites.[24] Low light transmission[23,25] associated with a decrease in depth of conversion has been previously reported for this material by other authors.[24,26,27] Furthermore, due to sonic activation, the deeper layer is likely to reach a more viscous consistency more rapidly in this material, reducing the mobility of molecules, consequently reaching the state of self-deceleration faster than the top and more fluid layers. Nevertheless, this composite is one of the materials with the highest conversions at 1, 2, and 3 mm and, despite statistical differences, it shows acceptable clinical values of conversion at 4 mm.

Regarding the EP material, in addition to containing conventional borosilicate glass filler particles, it also has E-glass fibers between 1 and 2 mm in length and

a diameter of approximately 16 micrometers.[28] It is well known that light transmission depends on the similarity between the refractive indexes of filler particles and of the organic matrix.[29] Thus, similar conversion results at different depths suggest the presence of such reinforcing fibers did not reduce the passage of light through the material. Consequently, high conversion values at greater depths have been reported for this material.[22,24]

The FBF composite, though it maintained constant conversion at 4 mm, presented lower conversion at the top increment than that observed in other materials, which possibly occurs as a function of its monomer composition. The VB resin, on the other hand, exhibited a uniform degree of conversion, higher than that of all other materials at the thickness of 4 mm, which can be explained by the fact that high translucency[11,23,24] and lower filler content[30] allowed for considerable light transmission and constant conversion from the top to the 4-mm depth. Other studies also reported higher conversion of VB compared to FBP on superficial layers and at 4 mm.[15,16]

Although Z350 showed a relatively low conversion, it presented a high volumetric shrinkage, while VB showed the highest degrees of conversion, but it had the lowest volumetric polymerization shrinkage. Such findings are interestingly unusual, because they are at odds with what is expected and commonly reported in the literature, where monomer conversion is directly proportional to volumetric shrinkage[3]. The low shrinkage of VB material is consistent with the study of Rosato et al.,[31] which evaluated post-gel shrinkage using a biaxial strain gauge method; however, it is not in line with other studies in which this material presented the highest shrinkage.[17,18] Lee et al.[30] showed that consistency of the composite is an important factor for determining axial shrinkage. Lower axial shrinkage is measured in more flowable composites due to the compensation of radial shrinkage that occurs more extensively in these materials.[30] In addition, in the bonded disc method, the composite is bonded to glass slides, which increases its factor C and limits its radial shrinkage when compared to the strain gauge method. Therefore, the low shrinkage of VB material can be explained by its very low viscoelastic properties in relation to the other composites,[27] which would increase radial shrinkage and consequently reduce axial shrinkage. In addition, it is believed that the relative lower inorganic content (38% by volume) was fundamental for this association, since smaller filler volumes imply greater translucency.[30] For the Z350 composite, the high inorganic content (66.3% by volume) may have attenuated light transmission,[30] resulting in lower conversion values. However, the high concentration of double bonds of TEGDMA, used as diluent monomer in Z350, may have increased its shrinkage. A similar shrinkage was observed for the flowable version of this material, ZF. Kim et al. observed a greater volumetric shrinkage of the Z350 composite compared to several bulk-fill composites, including FBP and SF.[32] Except for FBF, all bulk-fill resins presented lower shrinkage than the conventional Z350, which is important for the clinical application of these materials. In fact, several studies corroborate that bulk-fill composites have similar or lower volumetric shrinkage than conventional composites with the same consistency.[12,32,33]

All evaluated composites were non-toxic, which is of great importance for the maintenance of pulp vitality and health of gingival tissues. The toxicity of the resins is mainly due to the amount of unreacted monomers that can be released into the medium and is directly related to the degree of conversion,[34] and also due to their by-products and higher crosslink density.[35] Conventional composites, Z350 and ZF, which had a relatively low degree of conversion at 4 mm, also had the lowest cell viability, but the concentration of residual monomers released was not sufficient to cause intense cellular changes. It is important to highlight that these control materials are indicated for use at a thickness of 2 mm. In this experiment, a thickness of 4 mm was used for comparison to bulk-fill materials; consequently, the higher cytotoxicity could be expected at 4 mm. Notwithstanding, these materials were also classified as non-toxic, as well as all bulk-fill resins, when polymerized in 4-mm increments. A lower cell viability at the depth of 4 mm for conventional resins compared to bulk-fill resins had been previously reported by Toh et al.[19]

In addition to monomers types, other components of the organic matrix may have cytotoxic potential. An example is DMABEE,[36] co-initiator present at similar

concentrations in SF and FBF composites,[37] a lipophilic component[38] related to apoptosis and cell necrosis[36] due to its potential to induce cell membrane disruption.[39] Interestingly, the presence of DMABEE did not appear to increase the cytotoxic potential of SF compared to other materials. For FBF, on the other hand, it is possible to infer that the lower degree of conversion compared to SF at all depths led to lower cell viability.

The only materials with cell viability greater than 90% were SF and AB. Despite the controversial leaching potential of Bis-GMA,[40] the organic component of SF composite,[37] high filler content, and high degree of conversion and, consequently, a lower percentage of monomer residual and by-products and higher polymer network density[35] may have contributed to the low cytotoxicity of these materials. In addition, due to the peculiar rheology of SF, it is believed that the application of sonic energy during the insertion of the material may be able to facilitate the formation of a denser polymer network, which would decrease the leaching of potentially toxic unreacted components. It was not possible to gather information on the composition of AB composite. The information available on the manufacturer's website and on the Material Safety Data Sheet (MSDS) of the material is common to all products of the Aura composites and not specific to AB. However, the high degree of conversion of this material, even when smaller than 4 mm at the top of the restoration, may explain its low cytotoxicity. Besides the better biocompatibility of these two materials, none of the studied composites were toxic to gingival fibroblasts at the thickness of 4 mm; not even the Z350 material, where higher residual monomers are expected due to the polymerization mode. This is a positive finding and offers clinicians some confidence in the use of these new materials without adverse effects on the gingiva. However, it should be highlighted that some factors other than the material can affect biocompatibility, such as patient's immune response, tooth cavity status, cell type affected, among others.

Conclusion

Based on the findings described above and considering the limitations of the current study, it is possible to conclude that bulk-fill composites could be alternative restorative materials that should be considered by clinicians, as they are non-toxic and have similar or even lower volumetric shrinkage compared to conventional composites. Nevertheless, not all materials are able to maintain homogeneous conversion at a 4-mm thickness; most of them are able to reach a degree of conversion high enough for clinical application. No "ideal" material has been developed until now, so clinicians should be aware of the performance and limitations of the materials used in order to achieve the desired outcomes. In the present study, the VB composite showed better conversion at the 4-mm thickness with a smaller volumetric shrinkage and acceptable cytotoxicity.

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