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# Curing behaviour of high-viscosity bulk-fill composites

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ABSTRACT

*Objectives:* This study aimed to assess the effect of curing conditions – exposure time, mode, energy density, and exposure distance – on the mechanical properties of high-viscosity bulk-fill resin-based composites (RBCs) measured at simulated clinical relevant filling depths.
*Methods:* Three high-viscosity bulk-fill RBCs were investigated by assessing the variation in micromechanical properties in 200 μm steps (Vickers hardness [HV] and indentation modulus [E]) within simulated 6-mm deep fillings ($n = 5$) polymerized under 16 different curing conditions. The exposure duration was 5, 20, and 40 s in the standard power mode; 3, 4, and 8 s in the high power mode; and 3 and 6 s in the plasma mode; the exposure distance was 0 and 7 mm. Energy density ranged from 2.63 to 47.03 J/cm$^2$. Measurements were performed after 24 h of storage in distilled water at 37 °C. The depth of cure (DOC) was calculated as the 80% hardness drop-off.
*Results:* The results were compared using one- and multiple-way ANOVAs and Tukey's HSD post hoc test ($\alpha = 0.05$). The effect of the parameter material was significant and strong on all measured properties ($p < 0.05$, partial eta-squared $\eta_P^2 = 0.492$ for $E$, 0.562 for HV, and 0.087 for DOC). Energy density exerted the strongest influence on the measured properties in all materials, whereas the influence of the exposure distance was strong on DOC, low on $E$ and not significant on HV. The high-viscosity bulk-fill RBCs respond heterogeneously to variations in curing conditions.
*Conclusions:* A lower energy density limit was identified, allowing for a 4 mm material bulk placement (5.88 J/cm$^2$ for EvoCeram Bulk Fill, 7.0 J/cm$^2$ for x-tra fil, and 23.51 J/cm$^2$ for SonicFill). This limit increased to 47.03 J/cm$^2$ for a 5 mm bulk placement, as claimed for SonicFill. To maintain mechanical properties in depth, however, an energy density of at least 23.51 J/cm$^2$ is recommended for EvoCeram Bulk Fill and x-tra fil and 47.03 J/cm$^2$ for SonicFill, respectively. This energy density should be achieved at moderate irradiance and increased curing time.
*Clinical significance:* An exposure time of 20s at moderate irradiance is recommended for all materials for a 4 mm bulk placement.



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## 1. Introduction

The incremental layering technique is accepted as a golden standard for the placement of resin-based composite (RBC) restorations.[1] However, the latest developments in composite technology are materials intended for posterior bulk-filling placement, the so-called bulk-fill RBC. The materials can be applied in increments up to 4 mm thickness,[2–8] thus skipping the time-consuming layering process. Improved self-levelling ability,[9] decreased polymerization shrinkage stress,[10–12] reduced cusp deflection in standardized class II cavities,[13] and good bond strengths regardless of the filling technique and the cavity configuration[14] are reported.

On the basis of differences in viscosity and application technique, the materials are classified in low- and high-viscosity bulk-fill RBCs. The low mechanical properties of the former[15] require to finish a restoration by adding a capping layer made of regular RBCs. Regarding regular RBCs, the changes made in bulk-fill RBCs to enlarge the DOC addressed primarily the fillers, which generally increased in size in all materials and decreased in load in low-viscosity bulk-fill composites.[15] Large fillers (>20 μm), as observed in several materials (x-tra fil and x-tra base, VOCO, Cuxhaven, Germany; SureFil SDR flow, DENTSPLY Caulk, Milford, DE, USA; SonicFill, Kerr, Orange, CA, USA),[15] involve a lower total filler–matrix interface compared with regular composites, reducing light scattering and increasing the transmittance for blue light in the depth. The implementation of higher-molecular weight monomers (SureFil SDR flow) or new initiator systems (Ivocerin in Tetric EvoCeram Bulk Fill; Ivoclar Vivadent Inc., Amherst, NY)[16] are further attempts headed for the same purpose.

There is no general consensus on the adequate radiant exposure a material needs for proper polymerization because the susceptibility to variation in irradiance under simulated clinical conditions was often proven to be material dependent in both regular[17,18] and bulk-fill RBCs,[3,4] and calculations based on total energy delivered to guide irradiation protocols were shown to be invalid and to not recognize product behaviour.[17] Despite this evidence, the irradiance of modern curing units continues to increase, keeping stubbornly the assertion that an adequate polymerization might be reached at short exposure times (5 s or less) at high irradiances.

The aim of this study was therefore to evaluate the effect of 16 different radiant exposures, adjusted by varying the curing regime, the irradiance, the exposure time, and the exposure distance (i.e., distance between the unit and the specimen's surface) on the variation of Vickers hardness (HV) and indentation modulus (*E*) within the simulated 6 mm deep cavities field in bulk with three high-viscosity bulk-fill RBCs. Moreover, the study aims to assess the DOC at all above-mentioned radiant exposures and to determine the bandwidth for adequate curing in response to the application of light.

The tested null hypotheses were as follows: (1) the effect of the curing conditions would be similar in all materials; (2) there would be no difference within one material among the assessed curing conditions; and (3) there would be no difference in the mechanical properties and the DOC among the analyzed materials.

## 2. Materials and methods

Three high-viscosity bulk-fill RBCs were investigated (Table 1) by assessing the variation in micromechanical properties (HV and *E*) as a function of depth, irradiation mode, and exposure distance (0 and 7 mm). A blue-violet LED curing unit (VALO, Ultradent Products Inc., South Jordan, UT, USA) was therefore used in different curing modes and exposure times: standard power mode (5, 20, and 40 s), high power mode (3, 4, and 8 s), and plasma mode (3 and 6 s) and two exposure distances (0 and 7 mm) (Table 2), thus resulting in 16 different curing conditions for each material.

### 2.1. Irradiance measurements

The analysis of the variation in the irradiance of the curing unit VALO with the distance as well as at the bottom of the 6 mm specimens was performed on a laboratory-grade NIST-referenced USB4000 Spectrometer (Managing Accurate Resin Curing System; Bluelight Analytics Inc., Halifax, Canada). The miniature fibre optic USB4000 Spectrometer uses a 3648-element Toshiba linear CCD array detector and high-speed electronics. The spectrometer has been spectroradiometrically calibrated using Ocean Optics' NIST-traceable light source (300–1050 nm). The system uses a CC3-UV Cosine Corrector to collect radiations higher than the 180° field of

**Table 1 – Materials, manufacturer, chemical composition of matrix and filler as well as filler content by weight (wt.%) and volume (vol.%).**

| Bulk Fill RBCs | Manufacturer, colour, batch | Resin matrix | Filler | Filler wt.%/vol.% |
|---|---|---|---|---|
| Tetric EvoCeram® Bulk Fill Nano-hybrid RBC | Ivoclar Vivadent, IVA, P84129 | Bis-GMA, UDMA | Ba–Al–Si–glass, prepolymer filler (monomer, glass filler and ytterbium fluoride), spherical mixed oxide | 79–81 (including 17% prepolymers)/60–61 |
| X-tra Fil Hybrid RBC | Voco, Universal, 1230323 | Bis-GMA, UDMA, TEGDMA | | 86/70.1 |
| SonicFill™ Nano-hybrid RBC | Kerr, A3, 3851737 | Bis-GMA, TEGDMA, EBPDMA | $SiO_2$, glass, oxide | 83.5/– |

*Abbreviations*: Bis-GMA, bisphenol-A diglycidyl ether dimethacrylate; EBPDMA, ethoxylated bisphenol-A-dimethacrylate; TEGDMA, triethyleneglycol dimethacrylate; UDMA, urethane dimethacrylate. Data are provided by manufacturers.