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Bulk-fill Resin-based Composites: An *In Vitro* Assessment of Their Mechanical Performance

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Clinical Relevance

In an attempt to speed up the restoration process, a new class of resin-based composite (RBC) material, the bulk-fill RBC, was recently introduced on the market, enabling up to 4- or 5-mm thick increments to be cured in one step. Their mechanical properties vary relative to those of flowable and nonflowable nanohybrid and microhybrid RBCs.

SUMMARY

The study aimed to assess the mechanical performance of seven bulk-fill RBCs (Venus Bulk Fill, Heraeus Kulzer; SureFil SDR flow, Dentsply Caulk; x-tra base and x-tra fil, VOCO; Filtek Bulk Fill, 3M ESPE; SonicFill, Kerr; Tetric EvoCeram Bulk Fill, Ivoclar Vivadent) by determining their flexural strength (σ), reliability (Weibull parameter, m), flexural modulus ($E_{flexural}$), indentation modulus (Y_{HU}), Vickers hardness (HV), and creep (Cr).

The significant highest flexural strengths were measured for SonicFill, x-tra base, and x-tra fil, while x-tra base, SureFil SDR flow, and Venus Bulk Fill showed the best reliability. The differences among the materials became more evident in terms of $E_{flexural}$ and Y_{HU}, with x-tra fil achieving the highest values, while Filtek Bulk Fill and Venus Bulk Fill achieved the lowest. The enlarged depth of cure in bulk-fill RBCs seems to have been realized by enhancing the materials' translucency through decreasing the filler amount and increasing the filler size. The manufacturer's recommendation to finish a bulk-fill RBC restoration by adding a capping layer made of regular RBCs is an imperative necessity, since the modulus of elasticity and hardness of certain materials (SureFil SDR flow, Venus Bulk Fill, and Filtek Bulk Fill) were considerably below the mean values measured in regular nanohybrid and microhybrid RBCs.

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The class of bulk-fill RBCs revealed similar flexural strength values as the class of nanohybrid and microhybrid RBCs, and significantly higher values when compared to flowable RBCs. The modulus of elasticity ($E_{flexural}$), the indentation modulus (Y_{HU}), and the Vickers hardness (HV) classify the bulk-fill RBCs as between the hybrid RBCs and the flowable RBCs; in terms of creep, bulk-fill and the flowable RBCs perform similarly, both showing a significantly lower creep resistance when compared to the nanohybrid and microhybrid RBCs.

INTRODUCTION

Time-saving restorative materials are an ongoing demand for posterior applications. A new resin-based composite (RBC) material class, the bulk-fill RBCs, has been introduced in the past few years. They are an attempt to speed up the restoration process by enabling up to 4- or 5-mm thick increments to be cured in one step, thus skipping the time-consuming layering process. Bulk-fill RBCs are also marketed as restoratives that are particularly well suited for patients with limited compliance. Moreover, the rheology of these materials is thought to have changed, thus allowing a better adaption to the cavity walls and resulting in a self-leveling effect. For the same purpose, a sonic-activated bulk-fill RBC was also launched on the market (SonicFill, Kerr, Orange, CA, USA). In spite of the stated improved adaption to the cavity walls, microleakage analysis attested to a similar performance for bulk-fill RBCs (SDR, Dentsply Detrey, Konstanz, Germany), and x-tra base, VOCO, Cuxhaven, Germany) as for conventional RBC (GrandioSO, VOCO) in standardized Class II cavities.[1] The marginal integrity of posterior RBC (CeramX Mono, Dentsply; Tetric EvoCeram, Ivoclar Vivadent, Schaan, Liechtenstein; Filtek Supreme XT, 3M ESPE, Seefeld, Germany; and Venus Diamond, Heraeus Kulzer, Hanau, Germany) fillings to enamel and dentin, made with and without a 4-mm flowable base (SDR, Dentsply), was also similar, both, before and after thermomechanical loading.[2] However, the manufacturer's statements with regard to the incremental thickness were confirmed in *in vitro* studies, as the degree of cure and the micromechanical properties were shown to remain constant within a 4-mm layer at a irradiation time of up to 20 seconds (SDR, Dentsply; Venus Bulk Fill, Heraeus Kulzer).[3]

A main concern of curing large increments is a potentially increased polymerization shrinkage stress at the tooth-material interface. A bulk-fill material in its experimental version (SDR, Dentsply) revealed, however, that it had the lowest shrinkage stress and shrinkage-rate values in comparison to regular flowable and nonflowable nanohybrid and microhybrid methacrylate-based RBCs and a silorane-based microhybrid RBC.[4,5] Moreover, it was shown that bulk-fill flowable RBCs (SDR, Dentsply; x-tra base, VOCO) significantly reduced cuspal deflection in standardized Class II cavities compared with a conventional RBC (GrandioSO, VOCO) restored in an oblique incremental filling technique.[1] Regarding mechanical performance, bulk-fill materials (SDR, Dentsply) proved to be more rigid (higher modulus of elasticity) and more plastic (higher plastic deformation and creep values) when compared to regular flowable RBCs, and generally with lower mechanical properties than regular nanohybrid or microhybrid RBCs.[4] Other studies found, however, that bulk-fill RBCs exhibited a creep deformation within the range of regular RBCs.[6] They also found that the flexure strength, water uptake, and biocompatibility of bulk-fill RBCs (x-tra fil, VOCO) were comparable to conventional RBCs.[7]

The first bulk-fill material on the market, SureFil SDR flow (or SDR on the European market), as well as Venus Bulk Fill, x-tra base, and Filtek Bulk Fill, require an additional final capping layer made of regular RBCs, while other materials in the same category (SonicFill, Tetric EvoCeram Bulk Fill, and x-tra fil) can be placed without it. This different application of materials belonging to the same material class confuses many practitioners since they assume the materials' behavior would be similar.

The aim of this study was, therefore, to assess the mechanical performance of a new material class—the bulk-fill RBCs—at the macro and micro scale, and to compare its performance with an already published material database[8] determined under identical conditions, comprised of modern flowable and nonflowable nanohybrid and microhybrid RBCs.

The null hypotheses were: 1) there would be no significant difference in macromechanical (flexural strength [σ] and flexural modulus [$E_{flexural}$]) and micromechanical (Vickers hardness [HV], indentation modulus [Y_{HU}], and creep [Cr]) properties among the bulk-fill RBCs; and 2) there would be no significant difference in the above mentioned properties among the material class of bulk-fill RBCs and the class of flowable and nonflowable nanohybrid and microhybrid RBCs.

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MATERIALS AND METHODS

The seven bulk-fill RBCs on the market up to the present (Table 1) were analyzed. Only SonicFill was sonic activated; this was done with an oscillating handpiece (step 3), as recommended by the manufacturer.

The flexural strength (σ) and flexural modulus ($E_{flexural}$) were determined in a three-point bending test (n=20). Therefore, 140 samples were made by compressing the composite material between two glass plates with intermediate polyacetate sheets, separated by a steel mold having an internal dimension of $2 \times 2 \times 16$ mm. Irradiation occurred on the top and bottom of the specimens, as specified in ISO 4049:2009 standards[9]; the time of the light exposures was 20 seconds, with three light exposures, overlapping one irradiated section no more than 1 mm of the diameter of the light guide (1241 mW/cm^2, Elipar Freelight 2, 3M ESPE, Seefeld, Germany) to prevent multiple polymerizations. After removal from the mold, the specimens were ground with silicon carbide paper (grit size P 1200/4000 [Leco]) to remove protruding edges or bulges, and then stored for 24 hours in distilled water at 37°C. The samples were loaded until failure in a universal testing machine (Z 2.5, Zwick/Roell, Ulm, Germany) in a three-point bending test device, which was constructed according to the guidelines of NIST 4877 with a 12-mm distance between the supports.[10] During testing, the specimens were immersed in distilled water at room temperature. The crosshead speed was 0.5 mm/min. The universal testing machine measured the force during bending as a function of deflection of the beam. The bending modulus was calculated from the slope of the linear part of the force-deflection diagram.

Micromechanical Properties

Fragments larger than 8 mm (n=10) from the three-point bending test specimens of each group were used to determine the micromechanical properties (HV, Y_{HU}, Cr) according to DIN 50359-1:1997-10[11] by means of a universal hardness device (Fischerscope H100C, Fischer, Sindelfingen, Germany). Prior to testing, the samples were polished with a grinding system (EXAKT 400 CS, EXAKT, Norderstedt, Germany) using silicon carbide paper P 2500 followed by P 4000. Measurements were done on the top (n=10) of the slabs, about 4 mm away from the breaking edge, with six measurements per sample. The test procedure was carried out with controlled force, and the test load increased and decreased with a constant speed between 0.4 mN and 500 mN. The load and the penetration depth of the indenter were continuously measured during the load-unload-hysteresis. The universal hardness is defined as the test force divided by the apparent area of the indentation under the applied test force. From a multiplicity of measurements stored in a database supplied by the manufacturer, a conversion factor (0.0945) between universal hardness and HV was calculated by the manufacturer and entered into the software such

Table 1: *Materials, Manufacturer, and Chemical Composition of Matrix and Filler as Well as Filler Content by Weight (Wt) and Volume (Vol)*

Bulk Fill RBCs	Manufacturer, Color, Batch	Resin Matrix	Filler	Filler Wt%/Vol%
Tetric EvoCeram Bulk Fill nanohybrid RBC	Ivoclar Vivadent, IVA, P48872	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
Venus Bulk Fill nanohybrid RBC	Heraeus Kulzer, Universal 010026	UDMA, EBPDMA	Ba-Al-F-Si glass, SiO_2	65/38
SureFil SDR flow flowable base RBC	Dentsply Caulk, Universal, 100407	Modified UDMA, TEGDMA, EBPDMA	Ba-Al-F-B-Si glass and St-Al-F-Si glass as fillers	68/44
x-tra base hybrid RBC	VOCO, universal, V 45226	Bis-GMA, UDMA		75/
x-tra fil hybrid RBC	VOCO, universal 1202359	Bis-GMA, UDMA, TEGDMA		86/70.1
SonicFill nanohybrid RBC	Kerr, A3, 4252497	Bis-GMA, TEGDMA, EBPDMA	SiO_2, glass, oxide	83.5/
Filtek Bulk Fill nano RBC	3M ESPE, universal N387662	Bis-GMA, UDMA, Bis-EMA, Procrylat resins	Zirconia/silica, ytterbium trifluoride	64.5/42.5

Abbreviations: Bis-EMA, Bisphenol-A polyethylene glycol diether dimethacrylate; Bis-GMA, Bisphenol-A diglycidyl ether dimethacrylate; EBPDMA, ethoxylated Bisphenol-A-dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

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that the measurement results were indicated in the more familiar HV units. Y_{HU} was calculated from the slope of the tangent of the indentation depth-curve at maximum force. By measuring the change in indentation depth with a constant test force, a relative change in the indentation depth can be calculated. This is a value for the Cr of the materials.

Field Emission Scanning Electron Microscope

The structural appearance of the filler was established by a field emission scanning electron microscope (Zeiss Supra 55 VP, Zeiss NTS GmbH, Oberkochen, Germany) on unsputtered samples (Figure 1). Therefore, one fragment of the three-point bending test specimens of each group was ground and polished (P 4000) prior to examination. The backscattering method allows a distinction to become apparent between filler with different densities as well as to assess the fillers' sizes and morphologies.

Statistical Analysis

The Kolmogorov-Smirnov test was applied to verify that the data were normally distributed. The results were compared using one-way and multiple-way analysis of variance (ANOVA) and Tukey post hoc test (α=0.05). A multivariate analysis (general linear model with partial eta-squared statistics) assessed the effect of material, filler volume (%), and filler weight (%) on the mechanical properties (version 20.0, SPSS Inc, Chicago, IL, USA). A Pearson correlation analysis among the tested parameters was conducted, while the flexural strength data were additionally examined by means of a Weibull analysis.

A common empirical expression for the cumulative probability of failure P at applied stress is the Weibull model: $P_f(\sigma_c) = 1 - \exp[-(\sigma_c/\sigma_0)^m]$ where σ_c is the measured strength, m is the Weibull modulus, and σ_0 is the characteristic strength, which is defined as the uniform stress at which the probability of failure is 0.63. The double logarithm of this expression is: $\ln \ln[1/(1 - P)] = m\ln \sigma_c - m\ln \sigma_0$ By plotting $\ln \ln[1/(1 - P)]$ vs $\ln \sigma$, a straight line results with the upward gradient m.

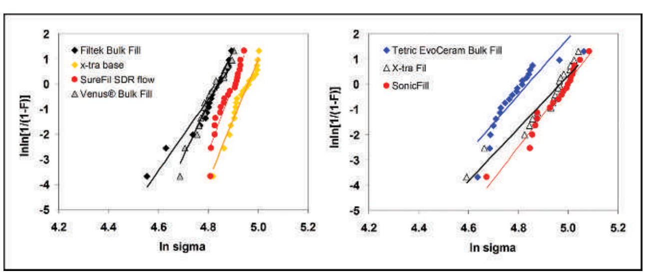

Figure 1. *Weibull analysis.*

RESULTS

Post hoc multiple pairwise comparisons with Tukey test ($p<0.05$) showed the significantly highest flexural strength values for SonicFill, x-tra base, and x-tra fil (Table 2). In terms of the material's reliability, expressed by the Weibull modulus (m), two groups can be distinguished, one comprising x-tra base, SureFil SDR flow, and Venus Bulk Fill, which are characterized by a very high Weibull modulus varying between 21.1 and 26.1, and the rest of the materials, showing a moderate reliability, with Weibull modulus values varying between 10.4 and 14.2 (Figure 1; Table 2). The differences among the materials became more evident in terms of $E_{flexural}$ and indentation modulus Y_{HU}. x-tra fil achieved the significantly highest values, whereas Filtek Bulk Fill and Venus Bulk Fill achieved the lowest. Moreover, an excellent correlation was measured between $E_{flexural}$ and Y_{HU} (Pearson correlation coefficient = 0.91). There was also a very good correlation within the micromechanical properties (Y_{HU} – HV = 0.94; Y_{HU} – Cr = –0.76; and HV – Cr = –0.64, whereas the correlation within the macromechanical properties was only moderate (FS – $E_{flexural}$ = 0.47).

The influence of the parameters bulk-fill RBC (material), filler volume, and filler weight were analyzed in an ANOVA multivariate test (Table 3). The filler volume and filler weight data were taken as indicated by manufacturers. The macromechanical properties (flexural strength and modulus of elasticity in flexural test) and the micromechanical properties (indentation modulus, Vickers hardness, and creep) were selected as dependant variables. The significance values of these three main effects were less than 0.05, indicating that they all contribute to the model. The results show that the strongest influence of the above mentioned parameters on the mechanical properties (higher eta square values) was reflected in the $E_{flexural}$ and Y_{HU}, followed by HV and Cr, while the influence on σ was moderate. Generally, the strongest influence on the measured properties was performed by the filler volume, followed by the filler weight, followed by material.

The material class of bulk-fill RBCs revealed similar flexural strength values when compared to the class of nanohybrid and microhybrid RBCs, and significantly higher values when compared to the class of flowable RBCs. $E_{flexural}$, Y_{HU}, and HV place

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Table 2: *Mechanical Properties (mean values with standard deviation in parentheses) Measured at Macroscopic Scale—Flexural Strength (σ) With Weibull Statistic (m = Weibull parameter, σ_0 = Characteristic Strength, R^2 = Regression Coefficient) and Flexural Modulus ($E_{flexural}$)—and Microscopic Scale—Indentation Modulus (Y_{HU}), Vickers Hardness (HV), and Creep (Cr)**

Bulk-fill RBC	σ, MPa	Weibull Statistic			$E_{flexural}$, GPa	Y_{HU}, GPa	HV, N/mm^2	Cr, %
		m	σ_0, MPa	R^2				
Tetric EvoCeram Bulk Fill	120.8[a] (12.7)	11.2	126.4	0.80	4.5[B] (0.8)	13.4[d] (0.8)	78.4[C] (6.7)	3.5[ab] (0.2)
Filtek Bulk Fill	122.4[ab] (9.6)	14.2	126.9	0.92	3.8[A] (0.4)	9.3[b] (0.2)	48.4[B] (1.3)	4.3[d] (0.1)
Venus Bulk Fill	122.7[ab] (6.9)	21.1	126.1	0.97	3.6[A] (0.4)	7.7[a] (2.0)	38.1[A] (11.8)	4.6[e] (0.4)
SureFil SDR flow	131.8[bc] (5.8)	26.6	134.5	0.91	5.0[B] (0.4)	11.3[c] (0.5)	54.2[B] (1.9)	4.0[c] (0.2)
x-tra fil	137.0[cd] (14.4)	10.4	143.8	0.92	9.5[E] (0.6)	22.2[g] (1.7)	133.5[D] (32.0)	3.4[a] (0.3)
x-tra base	139.4[cd] (7.0)	24.0	142.5	0.96	6.0[C] (0.9)	14.4[e] (1.1)	85.1[C] (11.2)	3.6[b] (0.3)
SonicFill	142.8[d] (12.9)	12.9	147.5	0.96	6.9[D] (0.6)	15.9[f] (0.7)	82.0[C] (4.7)	3.6[b] (0.2)

Abbreviations: RBC, resin-based composite.
** Superscript letters indicate statistically homogeneous subgroups within each column (Tukey test, α=0.05).*

the bulk-fill RBCs between the hybrid RBCs and the flowable RBCs. In terms of Cr performance, the bulk-fill RBCs and the flowable RBCs were similar, both showing a significantly lower creep resistance when compared to the nanohybrid and microhybrid RBCs.

Analyzing the amount of filler in the four material classes revealed a lower filler load in bulk-fill RBCs compared to the nanohybrid and microhybrid RBCs. Compared to the class of flowable RBCs, higher weight filler load was found for the bulk-fill RBCs, while the filler volume was similar in both material categories (Table 4).

DISCUSSION

Though advertised as a new material class, bulk-fill RBCs seem to not differ essentially in their chemical composition from regular nanohybrid and microhybrid RBCs.[8] They contain monomers like Bis-GMA, UDMA, TEGDMA, and EBPDMA in their organic matrix as well as regular filler systems (Table 1). In SureFil SDR flow, the organic matrix also contains a patent-registered urethane dimethacrylate with incorporated photoactive groups able to control polymerization kinetics[5] (SDR technology = stress decreasing resin). In Tetric EvoCeram Bulk Fill, the manufacturer states that, besides having a regular camphorquinone/amine initiator system, it has introduced an "initiator booster" (Ivocerin) able to polymerize the material in depth. However, there are few details concerning the polymerization mechanism or the chemical nature of the initiator. No changes in the polymerization initiating system are specified for the other bulk-fill materials; thus, the enlarged depth of cure must have been regulated by improving the materials' translucency. A simple approach in doing this is to reduce the amount of fillers since translucency and the amount of filler particles correlates linearly.[12] The statistical comparison among the material classes bulk-fill, nanohybrid, and microhybrid RBCs, with regard to the filler amount, confirms this assumption (Table 4). Besides, the translucency of dental materials is also influenced by the difference in the refractive indices between the filler particles and the resin matrix,[13,14] which determines how light is scattering within a material.[15] Similar refractive indices of the components of a RBC, as demonstrated for Bis-GMA and silica filler particles, were shown to improve translucency in experimental dental materials.[16] Apart from these considerations, the dimension of fillers was increased in many bulk-fill RBCs (x-tra fil, x-tra base, SureFil SDR flow, and SonicFill) (Figure 2) to a

Table 3: *Influence of Material, Filler Volume, and Weight on the Mechanical Properties—Flexural Strength (σ), Flexural Modulus ($E_{flexural}$), Indentation Modulus (Y_{HU}), Vickers Hardness (HV), and Creep (Cr)[a]**

Parameter	σ, MPa	$E_{flexural}$, GPa	Y_{HU}, GPa	HV, N/mm^2	Cr, %
Bulk-fill RBC	0.406	0.912	0.963	0.791	0.795
Filler vol%	0.279	0.943	0.968	0.794	0.852
Filler wt%	0.368	0.918	0.965	0.792	0.794

Abbreviations: RBC, resin-based composite.
[a] Table contains the partial eta-square values. The higher the partial eta-squares, the higher the influence of the selected factor on the measured properties.
** The influence of all parameters was statistically significant (α=0.05).*

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Table 4: *Mechanical Properties (mean values with standard deviation in parentheses) Measured at Macroscopic Scale—Flexural Strength (σ) and Flexural Modulus ($E_{flexural}$)—and Microscopic Scale—Indentation Modulus (Y_{HU}), Vickers Hardness (HV), and Creep (Cr) as Well as Filler Weight (Wt) and Volume (Vol) for Different RBC Categories**

RBC Type	σ, MPa	$E_{flexural}$, GPa	Y_{HU}, GPa	HV, N/mm^2	Cr, %	Wt, %	Vol, %
Microhybrid RBC	131.2^A (29.8)	7.3^a (2.6)	14.9^A (4.9)	87.0^a (28.8)	3.6^A (0.5)	78.5^a (4.0)	62.8^A (12.5)
Nanohybrid RBC	125.9^A (32.6)	6.3^b (2.1)	14.8^A (5.5)	90.9^a (35.6)	3.6^A (0.5)	78.2^a (7.9)	63.8^A (8.7)
Bulk fill	131.1^A (13.3)	5.6^c (2.0)	13.5^B (4.6)	74.3^b (32.6)	3.9^B (0.5)	73.1^b (8.0)	51.0^B (12.2)
Flowable RBC	119.3^B (25.8)	4.2^d (1.3)	10.6^C (3.6)	65.8^c (28.9)	3.8^B (0.6)	69.9^c (8.2)	51.1^B (10.6)

Abbreviations: RBC, resin-based composite.
** Superscript letters indicate statistically homogeneous subgroups within each column (Tukey test, α=0.05).*

size of 20 μm or more, which decreases, at a similar filler amount, the total filler surface and, consequently, the filler-matrix interface. Thus, light scattering at the filler-matrix interface is reduced, allowing more light to penetrate the material and to better cure the RBCs in depth. Moreover, four of the analyzed bulk-fill RBCs are denoted as nano or nanohybrid RBCs (Table 1), containing a certain amount of low-sized fillers. With dimensions below the wavelength of visible light (390 to 750 nm), nanoparticles are unable to scatter or absorb visible light, which is an important aspect in light curing and improves translucency and esthetics.[17]

Assuming that the bulk-fill RBCs are adequately cured and the mechanical properties within the incremental thickness are constant,[3] the mechanical stability in stress-bearing areas of fillings restored with this material class is still an open question, since, so far, long-term clinical studies are not available. Comprehensive reviews of the past years, analyzing the reasons of clinical failures in RBC restorations, indicate an increased trend in material fracture.[18,19] Moreover, the mechanical properties of modern RBCs are significantly weaker and less fracture resistant than those sold in the 1970s and 1980s, before the major push to minimize particle size occurred,[20] which brings into question whether modern RBCs are strong enough under clinical conditions. When comparing the material classes, the bulk-fill RBCs showed significantly lower mechanical properties, except for flexural strength, than the nanohybrid and microhybrid RBCs (Table 4). Since it is a parameter of decisive importance, it is most important to note that the modulus of elasticity is lower in the bulk-fill RBCs than in the nanohybrid and microhybrid RBCs. A material with a low modulus of elasticity, particularly when placed in load-bearing areas, will result in a higher deformability under masticatory stresses. This will cause, as a final consequence, catastrophic failures.

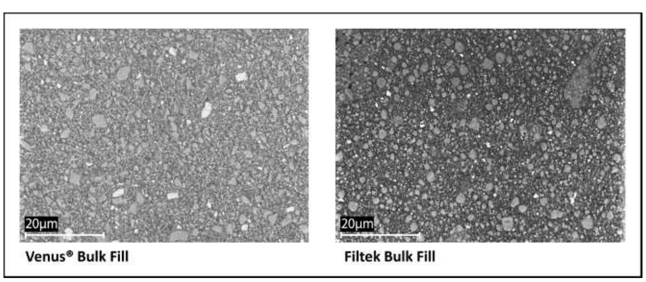

Figure 2. *Structural appearance of the filler established by field emission scanning electron microscopy (backscattering mode).*

Within the bulk-fill RBCs, the material with the highest filler content, x-tra fil, (Table 1) also achieved the highest modulus of elasticity, while a lower filler content was clearly reflected in lower Y_{HU} and $E_{flexural}$ values (Filtek Bulk Fill and Venus Bulk Fill). Thus, the excellent correlation between filler amount and modulus of elasticity measured for RBCs in previous studies[8,21,22] is confirmed. An exception is Tetric EvoCeram Bulk Fill, which shows moderate values for the modulus of elasticity, albeit having a high filler content. It must, however, be considered that Tetric EvoCeram Bulk Fill also contains prepolymerized fillers, which is included in the total filler amount. Thus, the inorganic filler content, which in effect increases the modulus of elasticity, is consistently lower (Table 1).

The material's reliability, expressed in this study by the Weibull modulus (m), neither correlated with the filler amount (Table 1) nor with the filler shape or dimension. Of the three materials with high reliability, x-tra base and SureFil SDR flow included very large fillers (>20 μm) in their formulation, while the filler system in Venus Bulk Fill resembled the structure of regular RBCs (Figure 2). Also, the sonic-activated bulk-fill RBC SonicFill, with a supposed improved flowability and therefore reduced surface defects able to initiate crack propagation, showed only a moderate reliability. As a consequence, additional rheologic measurements are necessary to evaluate the effect of filler size and amount on the flowability of bulk-fill materials.

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When using bulk-fill materials, the manufacturers indicate to either finish the restoration by adding a capping layer made of regular RBCs (SureFil SDR flow, Venus Bulk Fill, x-tra base, and Filtek Bulk Fill) or to place the bulk-fill RBCs without capping (SonicFill, Tetric EvoCeram Bulk Fill, and x-tra fil). While in terms of flexural strength the reason for this indication is not evident (Table 2), the measured values for the modulus of elasticity, indentation modulus, and hardness, except for x-tra base, clearly confirm manufacturer indications. Bulk-fill RBCs like SureFil SDR flow, Venus Bulk Fill, and Filtek Bulk Fill reached HV values (38.1-54.2 N/mm^2) considerably below the mean values measured in regular nanohybrid and microhybrid RBCs (90.9 N/mm^2 and 87.0 N/mm^2, respectively); thus, an additional final capping layer is necessary. Moreover, the very large particle size in four of the analyzed materials (Figure 2) could increase surface roughness[23] and renew the discussion about abrasion, attrition, and wear in RBCs.[24]

Both tested null hypotheses are therefore rejected. The measured properties allow a direct comparison of the bulk-fill RBCs with regular RBCs and place them, as a material category, between the hybrid (nano and micro) RBCs and the flowable RBCs. It must, however, be considered that the flexural strength was measured in this study on 2-mm thick samples, as specified in ISO standards, while bulk-fill RBCs are clinically applied in larger increments. Since the degree of cure and the micromechanical properties were shown to remain constant within a 4-mm layer in two of the materials analyzed in this study (SureFi SDR flow and Venus Bulk Fill),[3] it can be assumed that under proper polymerization conditions, a 4-mm increment placed with these materials in bulk or by using an incremental technique would present similar properties.

CONCLUSIONS

The manufacturers' indication to finish a bulk-fill RBC restoration by adding a capping layer made of regular RBCs is a necessity, since the indentation modulus and hardness of particular materials (SureFil SDR flow, Venus Bulk Fill, and Filtek Bulk Fill) were considerably below the mean values measured in regular nanohybrid and microhybrid RBCs.

The measured mechanical properties place the bulk-fill RBCs, as a material category, between the nanohybrid and microhybrid RBCs and the flowable RBCs, suggesting a similar or even inferior clinical behavior of bulk-fill RBCs compared to nanohybrid and microhybrid RBCs. Within the class of bulk-fill RBCs the differences in mechanical properties among the RBCs are, however, large.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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REFERENCES

1. Moorthy A, Hogg CH, Dowling AH, Grufferty BF, Benetti AR, & Fleming GJ (2012) Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials *Journal of Dentistry* **40(6)** 500-505.
2. Roggendorf MJ, Kramer N, Appelt A, Naumann M, & Frankenberger R (2011) Marginal quality of flowable 4-mm base vs. conventionally layered resin composite *Journal of Dentistry* **39(10)** 643-647.
3. Czasch P, & Ilie N (2012) *In vitro* comparison of mechanical properties and degree of cure of bulk fill composites *Clinical Oral Investigations* **17(1)** 227-235.
4. Ilie N, & Hickel R (2011) Investigations on a methacrylate-based flowable composite based on the SDR technology *Dental Materials* **27(4)** 348-355.
5. Jin X BS, & Hammesfahr PD (2009) New radically polymerizable resins with remarkably low curing stress *Journal of Dental Research* **88(Special Issue A)** 1651.
6. El-Safty S, Silikas N, & Watts DC (2012) Creep deformation of restorative resin-composites intended for bulk-fill placement *Dental Materials* **28(8)** 928-935.
7. Fleming GJ, Awan M, Cooper PR, & Sloan AJ (2008) The potential of a resin-composite to be cured to a 4mm depth *Dental Materials* **24(4)** 522-529.
8. Ilie N, Rencz A, & Hickel R (2012) Investigations towards nano-hybrid resin-based composites *Clinical Oral Investigations* **17(1)** 185-193.
9. ISO Standards (2009) ISO 4049 Dentistry – polymer-based restorative materials *Geneve: International Organization for Standardization [edition 4-28].*
10. Quinn GD (1992) *Room-Temperature Flexure Fixture for Advanced Ceramics NISTIR 4877* National Institute of Standards and Technology, Gaithersburg, MD.
11. DIN Standards (1997) DIN-50359-1 Testing of metallic materials - Universal hardness test - Part 1: Test method
12. Lee YK (2008) Influence of filler on the difference between the transmitted and reflected colors of experimental resin composites *Dental Materials* **24(9)** 1243-1247.
13. Primus CM, Chu CC, Shelby JE, Buldrini E, & Heckle CE (2002) Opalescence of dental porcelain enamels *Quintessence International* **33(6)** 439-449.
14. Shortall AC, Palin WM, & Burtscher P (2008) Refractive index mismatch and monomer reactivity influence composite curing depth *Journal of Dental Research* **87(1)** 84-88.

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15. Lee YK, Lu H, & Powers JM (2005) Measurement of opalescence of resin composites *Dental Materials* **21(11)** 1068-1074.

16. Azzopardi N, Moharamzadeh K, Wood DJ, Martin N, & van Noort R (2009) Effect of resin matrix composition on the translucency of experimental dental composite resins *Dental Materials* **25(12)** 1564-1568.

17. Kim JJ, Moon HJ, Lim BS, Lee YK, Rhee SH, & Yang HC (2007) The effect of nanofiller on the opacity of experimental composites *Journal of Biomedical Materials Research. Part B, Applied Biomaterials* **80(2)** 332-338.

18. van Dijken JW (2000) Direct resin composite inlays/onlays: An 11 year follow-up *Journal of Dentistry* **28(5)** 299-306.

19. Van Nieuwenhuysen JP, D'Hoore W, Carvalho J, & Qvist V (2003) Long-term evaluation of extensive restorations in permanent teeth *Journal of Dentistry* **31(6)** 395-405.

20. Ferracane JL (2013) Resin-based composite performance: Are there some things we can't predict? *Dental Materials* **29(1)** 51-58.

21. Ilie N, & Hickel R (2009) Investigations on mechanical behaviour of dental composites *Clinical Oral Investigations* **13(4)** 427-438.

22. Masouras K, Silikas N, & Watts DC (2008) Correlation of filler content and elastic properties of resin-composites *Dental Materials* **24(7)** 932-939.

23. Poggio C, Dagna A, Chiesa M, Colombo M, & Scribante A (2012) Surface roughness of flowable resin composites eroded by acidic and alcoholic drinks *Journal of Conservative Dentistry* **15(2)** 137-140.

24. Condon JR, & Ferracane JL (1996) Evaluation of composite wear with a new multi-mode oral wear simulator *Dental Materials* **12(4)** 218-226.

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