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Physical Properties of a New Sonically Placed Composite Resin Restorative Material

ABSTRACT

A new nanohybrid composite activated by sonic energy (SonicFill, Kerr) has been recently introduced as a single-step, bulk-fill restorative material. The purpose of this study was to compare the physical properties of SonicFill to various other representative composite restorative materials. The following physical properties were examined: depth of cure, volumetric shrinkage, flexural strength/modulus, fracture toughness, and percent porosity. A mean and standard deviation were determined per group. A 1-way ANOVA/Tukey test was performed per property (alpha=0.05). Percent porosity was evaluated with a Kruskal-Wallis/Mann-Whitney test (alpha=0.005). Significant differences were found between groups ($p<0.001$) per test type. Compared to the other composite restorative materials, SonicFill showed low shrinkage and percent porosity, high strength/flexural modulus and fracture toughness. However, depth of cure was less than manufacturer's claim of 5mm.

INTRODUCTION

Composite resin was first introduced in the 1960's as an alternative to acrylic resins for esthetic dental restorations.[1] Initially these materials performed poorly, but increased popularity and demand for esthetic restorations have driven continued improvement in strength, wear resistance, handling, and esthetics.[2] For many years composite resin restorations have been considered an acceptable treatment choice for anterior applications.[3] However, it is generally accepted that composite resin

restorations in the posterior still have limitations and that there is no one ideal material available.[4]

A volumetric shrinkage of 1% to 6% occurs when a composite resin material is cured.[1] The shrinkage is the result of the conversion of monomer molecules into a denser polymer network which leads to bulk contraction.[5] *In vivo* studies have demonstrated the percentage of marginal gaps in a composite resin restoration may vary between 14% and 54% depending on the materials and technique.[6] The resulting marginal gap may provide a site for recurrent caries which is cited as the most common cause of failure for composite resins.[7] In spite of significant advances in composite resin composition, a decrease in microleakage and gap formation did not follow at a similar rate.[8]

Another concern regarding composite resin placement is depth of cure. When composite resin is applied as a single bulk layer, there is a low degree of polymerization at the depth of deeper cavity preparations due to attenuation of the light.[1] Products marketed as posterior packable composite resins reportedly allowed bulk curing up to 5 mm, however laboratory studies did not substantiate these claims.[9] Uncured composite resin at the base of a restoration can cause microleakage with resulting pulpal sensitivity, staining, and recurrent caries.[10] Additionally, incomplete curing of composite resins is associated with a reduction in the mechanical properties of the material.[11]

Historically, composite resin restorations have been advocated for use in areas of minimal stress.[10] However, increased demand has led to greater use on posterior teeth, where considerable mechanical challenges occur under function.[12] To withstand

these stresses, modification of filler particle size and morphology has resulted in improved mechanical properties.[13] Elastic modulus is directly related to filler loading, therefore it could be assumed that heavily filled composite resins would have improved mechanical strength, fracture properties, and wear resistance.[3,14] However, maximum filler volume is about 70% because poor handling characteristics and technical difficulties, such as decreased wetability, can result from overloading.[15] Filler content not only directly determines the mechanical properties of composite resin but also allows for reduction in monomer content, improves handling properties and influences wear resistance, translucency, opalescence, radiopacity, intrinisic surface roughness, and polishability.[16]

Another clinical aspect of concern regarding composite resins is their handling characteristics. The ability of a composite material to flow plays a major role in the ultimate success of a restoration.[17] However, in many class II cavity preparations, it is more difficult to obtain proper contour and achieve adequate proximal contacts because composite resin is not packable.[18] The desire for composite resins with certain flow characteristics has been addressed by the introduction of packable and flowable composite resins. Packable composite resins were first introduced as an alternative to amalgam.[10] They are characterized by a high filler load and a filler distribution that gives them a different consistency when compared with traditional composite resins.[19] Whereas flowable composite resins contain lower filler concentrations, and are characterized by a lower elastic modulus and viscosity.[19] For the average clinician, the ideal resin-based composite resin material would be viscous enough to facilitate ease of placement but low enough for adequate margin adaptation.[20]

A new composite resin material on the market by Kerr (Orange, CA), SonicFill, claims to address many of the problems listed above. SonicFill is a single-step, bulk-fill composite resin system that reportedly can be used in cavity preparations up to 5mm deep. Sonic activation purportedly lowers the viscosity of the material to allow for easy adaptation to cavity walls. The company claims that after placement, the composite resin returns to a non-slumping state that allows for easy contouring. Company research shows up to 5mm of bulk-placed composite resin can achieve a full depth of cure with low volumetric shrinkage and high strength properties (www.kerrdental.com).

To fully understand SonicFill's place in a clinician's daily practice, one must first understand the different types of composite resins available on the market. Most dental composite resin materials are composed of a polymeric matrix (typically dimethacrylate), reinforcing fillers (typically radiopaque glass), a silane coupling agent to bind the filler to the matrix and chemicals that promote or modulate the polymerization reaction.[4] Because of the major influence of fillers on the physical properties of dental composite resins, their classification is based on the type and particle size of fillers.[21] Currently, the most traditional methacrylate composite resins for restorative purposes are the hybrid and microfill types.[22] Microfill composite resins were formulated with fillers having an average particle size in the range of 0.01-0.05 μm and prepolymerized particles approximately 50 μm in size. These composite resins were designed to overcome the problems of poor esthetic properties.[21] However, mechanical properties are too low for applications in areas of high functional stress.[21] Hybrids offer intermediate esthetic properties but excellent mechanical properties by the incorporation of fillers with different average particle sizes, 15-20 μm and 0.01-0.05 μm.[22] A recent

development with methacrylate-based composites has been nanocomposites, which contain nanoscale particles and nanohybrids, which contain a mixture of nanoscale particles and larger particles.[4] The manufacturers claim that nanocomposites (e.g., Filtek Supreme Ultra, 3M/ESPE) combine the mechanical strength of hybrids and superior polishabiliy of microfills, in addition to high wear resistance and reduced polymerization shrinkage.[22] In general it is difficult to discern between nanohybrids and microhybrids because many manufacturers have simply modified their microhybrid composition to include more nanoparticles or even pre-polymerized resin fillers.[4] The physical properties of flexural strength and modulus of elasticity of nanohybrids and microhybrids tend to be similar.[4] SonicFill and Tetric EvoCeram Bulk Fill (Ivoclar Vivadent, Amherst, NY) are marketed as nanohybrid composite resins, while Quixx (Dentsply, Milford DE) and Filtek Z250 (3M/ESPE, St. Paul, MN) are hybrid composite resins. In addition to the traditional composite resins, a unique posterior composite resin, Filtek LS, has recently been developed by 3M/ESPE. Instead of the conventional methacrylate-derived monomer, Filtek LS utilizes a silorane monomer ring. It demonstrates similar mechanical properties compared to methacrylate composite resins but the distinct advantage is its reduced polymerization shrinkage. The expansion of the ring before polymerization has been shown to decrease the polymerization shrinkage to less than 1.5%.[23] SonicFill, Tetric EvoCeram and Quixx have been recently marketed as restorative materials that can be placed in increments of four or more millimeters. Very little information has been published on this new class of bulk-fill materials.

The purpose of this study was to compare the physical properties of the new sonically placed composite resin to other composite resin materials marketed for posterior restorations. The null hypothesis tested was that there would be no significant difference in physical properties between the various composite resin restorative materials per property.

METHODS AND MATERIALS

The composite resins used in this study included SonicFill, shade A2, by Kerr; Quixx, universal shade, by Dentsply; Tetric EvoCeram Bulk Fill, shade IVA, by Ivoclar Vivadent; Filtek LS, shade A2, and Filtek Z250, shade A2, by 3M ESPE (see Table 1). The following properties were evaluated: depth of cure, volumetric polymerization shrinkage, flexural strength/modulus, fracture toughness, and internal porosity.

To determine depth of cure, the composite resins were tested using the scraping technique (ISO 4049). Five specimens per group were created. A 4-mm diameter by 14-mm long stainless-steel split mold (Sabri, Downers Grove, IL) was placed on a plastic-strip-covered glass slide on a standard white background. The composite resin was injected into the mold and a plastic strip was placed. The composite resin was condensed with a glass slide to displace excess resin. The glass slide was removed and the specimens were immediately polymerized with a curing light (Bluephase G2 LED, Ivoclar, Amherst, NY) for 20 seconds. Each specimen was polymerized at a distance of 0 millimeters utilizing a clamp to hold the curing light. The light emission from the Bluephase G2 was analyzed with a spectrophotometer (Blue Light Analytics, Halifax, Canada). The curing light was connected to a power cord to provide

continuous, consistent operation. The emitted light was analyzed during a 20 second curing cycle and the following data was collected: mean irradiance - 1132 mW/cm^2; total energy density - 22.8 J/cm^2; spectral/energy distribution – 360 - 420 nm – 4.2 J/cm^2; 420 - 540 nm – 18.6 J/cm^2. The uncured resin was then scraped with a plastic instrument starting from the deepest point on the underside of the mold until polymerized resin was reached. The composite resin was removed from the mold and the length of the remaining polymerized material was measured with an electronic digital caliper (GA182, Grobet Vigor, Carlstadt, NJ) and divided by two, according to the ISO standard.

To determine polymerization shrinkage, the composite resins were placed on a pedestal in the video-imaging device (AcuVol, Bisco, Schaumberg, IL). Ten specimens per group were imaged from the side at a distance of 10cm. The video camera digitized and analyzed the images with the provided image-processing software. The specimens were light cured for 40 seconds using the curing light unit as before. Polymerization shrinkage was recorded continuously for 5 minutes after the light initiation.

To determine flexural strength/modulus, each specimen was prepared in a 2x2x25mm stainless-steel mold (Sabri) placed on a plastic-strip-covered glass slide. Ten rectangular specimens per each of the restorative materials were made by inserting the restorative material into the mold. The top surface of the mold was covered with a second plastic strip and glass slide as before. One side of the specimen was exposed to a light polymerization unit for 20 seconds each in five separate overlapping increments. Next, the mold was turned, and the opposite side of the specimen was exposed to the light in a similar manner. Then, the specimens were removed from the

mold and stored in distilled water at an intra-oral temperature of 37°C for 24 hours. Each specimen was placed on a three-point bending test device which was constructed with a 20mm span length between the supporting rods. The central load was applied with a head diameter of 2mm, and a crosshead speed of 0.25mm/min using the universal testing machine (MTS, Eden Prairie, MN). The flexural strength was calculated using the equation:

$$\sigma_{FS} = \frac{3Fl}{2bd^2}$$

where *F* is the loading force at the fracture point, *l* is the length of the support span (20mm), *b* is the width, and *d* is the depth (for our case, *b* = *d* = 2mm). Measurements were made using the electronic digital caliper. Flexural modulus was determined from the slope of the linear region of the load-deflection curve using the analytical software (TestWorks 4, MTS).

Fracture toughness was determined by a single-edge notched-beam method. To prepare each specimen, a knife-edged split 2x2x25mm stainless-steel mold was placed on a plastic strip-covered glass slide as before. Ten specimens per each of the restorative materials were made by inserting the restorative material into the mold (Sabri) until completely filled. Then, the top surface of the mold was covered with a second plastic strip and glass slide as before. One end of the specimen was then exposed to a light polymerization unit for 20 seconds each in five separate overlapping increments. Next, the mold was turned over, and the opposite side of the specimen was exposed to the light in a similar manner. The specimens were stored as before and after 24 hours the notched specimens were fractured in the universal testing machine

(MTS) similar to flexural strength testing at crosshead speed of 1.0mm/min, with the notch on the tensile side. The load-deflection (*F* = load vs. u = deflection) curves were recorded; the height, *h*, and width, *w*, of the specimens were measured with the inside jaws of an electronic digital caliper as before and the notch depth, *a*, with a measuring stereo microscope (Nikon SMZ-1B) at 10X. Fracture toughness (K_{IC}) was calculated from measurements with the single-edge notched-bend specimens using the equation:

$$K_{IC} = \frac{3(a/w)^{1/2}[1.99 - a/w(1-a/w)(2.15 - 3.93a/w + 2.7(a/w)^2]FS}{2(1+2a/w)(1-a/w)^{3/2}hw^{3/2}}$$

where *S* is the span distance (20mm) between supports.

To evaluate internal porosity, 10 specimens were made in a plastic mold (Sabri), 2-mm long and 8-mm in diameter, which was placed on a plastic-strip-covered glass slide. The restorative materials were injected into the mold until completely filled. Both ends of the specimen were exposed to a visible-light polymerization unit as before for 20 seconds. After storage for 24 hours as before, they were placed in a microtomography unit (Skyscan 1172, Kontich, Belgium) and scans of the samples were made. Recorded images were then reconstructed (NRecon, version 1.4.4, Skyscan) into three-dimensional images which were analyzed using proprietary software (CT Analyzer, version 1.6.0.0, Skyscan) for percent porosity.

A mean and standard deviation were determined per group. Data was analyzed with a one-way ANOVA and Tukey's post hoc tests per test type ($\alpha = 0.05$). Due to the non-normal distribution of the data, percent porosity was evaluated with the non-parametric Kruskal-Wallis and Mann-Whitney tests. A Bonferroni correction was applied because multiple comparison tests were completed simultaneously ($\alpha = 0.005$).

RESULTS

Significant differences were found between groups per test type. See Figures 1-6. Groups joined by a vertical line were not significantly different. Quixx had the highest depth of cure (6.31mm), low shrinkage (2.00%), high strength/flexural modulus (111.86 MPa/13.34 GPa) and fracture toughness (0.61 MPa $m^{1/2}$), but it had the largest percentage of porosities (1.42%). SonicFill showed an above average depth of cure (3.67mm), low shrinkage (1.88%), high strength/flexural modulus (136.81 MPa/10.32 GPa), and fracture toughness (0.56 MPa $m^{1/2}$), and had the lowest percentage of porosities (0.02%). Tetric EvoCeram Bulk Fill had the second highest depth of cure (4.08mm) but the largest polymerization shrinkage (2.31%), high strength/flexural modulus (101.41 MPa/8.55 GPa), and fracture toughness (0.52 MPa $m^{1/2}$), and average percentage of porosities (0.40%). Filtek LS had the lowest depth of cure (2.06mm), but also the lowest shrinkage (1.21%), high strength/flexural modulus (113.80 MPa/9.17 GPa) and fracture toughness (0.52 MPa $m^{1/2}$), and average percentage of porosities (0.44%). And finally Filtek Z250 had an above average depth of cure (3.79mm), low shrinkage (2.00%), high strength/flexural modulus (139.41 MPa/10.86 GPa), the highest fracture toughness (0.62 MPa $m^{1/2}$), and average percentage of porosities (0.13%).

DISCUSSION

The null hypothesis was rejected in this study. Statistically significant differences were found between composite resins per test type. This would agree with the concept that different composite resins demonstrate a variety of mechanical properties with no

one type clearly the superior product.[16] One of SonicFill's primary claims is the ability to be utilized as a "single-step bulk fill product . . . on cavities up to 5mm", however, this study would not support that statement. The composite resin which had the highest depth of cure was Quixx at 6.31mm, which exceeded the manufacturer's claim of 4.2mm. This may be due to more translucent appearance of Quixx when fully cured. Tetric EvoCeram also met manufacturer's claim of a 4mm bulk fill, as did Filtek Z250 at a manufacturer's claim of 2.5mm. At 2.06mm Filtek LS did not meet the manufacturer's claim of a depth of cure to 2.5mm.

All composite resins tested showed high flexural strength/modulus and fracture toughness, although there were statistically significant differences between groups. This is because hybrids and nanohybrids do not differ significantly from each other as material types, though large varieties can be found between materials within the same category.[16] Current dental composite resins have adequate mechanical properties for use in all areas of the mouth, so other variables such as polymerization shrinkage and shrinkage stress, and durability of the bond may be of greater importance.[4]

Polymerization shrinkage has been steadily reduced through improvements in chemistry and composition.[8] A new composite resin, Filtek LS is promoted as an epoxy-based silorane composite resin with low shrinkage based on a ring-opening polymerization mechanism. Filtek LS had the lowest shrinkage of all of the composite resins tested at 1.21%. However, all the composite resins tested exhibited relatively low shrinkage. An average volumetric shrinkage of 1% to 6% occurs when composite resins are cured[1] and the highest degree of shrinkage in this study was 2.31% for Tetric EvoCeram Bulk Fill, which was still at the low end of the spectrum.

There is currently a lack of research evaluating the effect of porosities on the mechanical properties, marginal adaptation, or long-term performance in a composite resin restoration. With the new sonically placed composite resin, it was unknown if sonic energy would induce more porosities. The results of this study showed less porosity, at least within the body of the restoration, as compared to other composite resins marketed for posterior use as shown in Figure 7. Marginal adaptation and microleakage studies were not evaluated in this study.

CONCLUSION

Compared to the other posterior composite resin restorative materials, SonicFill had low shrinkage and percent porosity, and high flexural strength, modulus and fracture toughness. However, depth of cure was less than the manufacturer's claim of 5mm. Further research is necessary to evaluate the new class of bulk-fill restorative composites.

DISCLOSURE

The views expressed in this study are those of the authors and do not reflect the official policy of the United States Air Force, the Department of Defense, or the United States Government. The authors do not have any financial interest in the companies whose materials are discussed in this article.

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