Microcomputed tomographic comparison of posterior composite resin restorative techniques: sonicated bulk fill versus incremental fill

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Sonication technology has recently been touted to decrease composite viscosity during delivery and may allow better cavity preparation adaptation and minimize voids. The purpose of this investigation was to evaluate the difference between conventional, hand-placed, incremental application of a standard hybrid resin-based composite (RBC) and sonicated application of a bulk-fill RBC in box-type and cylindrical cavity preparations. Experimental restorations were fabricated using molds of box-type or cylindrical preparations. For bulk-filled specimens, a single compule of bulk-fill composite was dispensed with a sonic handpiece. The conventional hybrid material was placed in 3 increments (2 mm, 2 mm, and 1 mm). Microfocus X-ray computed tomography was used to analyze voids for percentage and total volume porosity as well as number of actual pores. An analysis of variance indicated that RBC restorations that were applied to cylindrical cavities using a sonicated bulk-filled application method exhibited significantly less porosity (1.42%; $P < 0.001$) than incrementally placed cylindrical restorations (2.87%); sonicated bulk-filled, cube-shaped restorations (3.12%); and incrementally placed cube-shaped restorations (5.16%). When the groups were subcategorized into the specific characteristics of shape (cube vs cylinder) and application method (bulk vs incremental), the cylindrical group, which included both bulk-filled and incrementally placed specimens, demonstrated significantly less porosity (2.00%; $P < 0.001$) than other groups. Restorations that were incrementally placed into cube-shaped cavities produced the largest amount of porosity.

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In 1999, the number of direct resin-based composite (RBC) restorations placed in the United States outnumbered amalgam restorations for the first time.[1] This trend has not only continued but also significantly increased.[2] Many researchers have expressed concerns about direct bonded composite resin restorations, including problems with polymerization shrinkage, marginal leakage, accelerated wear, unpolymerized resin, fracture, and difficulty in establishing good proximal contacts.[3-14] However, another negative observation has largely been ignored: the presence of voids within the final restoration due to application techniques. These voids may cause marginal leakage, discoloration, increased wear due to stress concentration around voids, decreased flexural strength, and incomplete adhesion between the resin and tooth surface.

This aspect of RBC restorations has not been well documented, because advanced techniques to characterize and quantify voids in 3 dimensions were not available until the recent advent of microcomputed tomography (µCT). To minimize the size and number of voids and porosity within RBC restorations, a novel resin composite delivery system, using sonication technology to decrease the viscosity of the composite material during delivery, may allow for better cavity preparation adaptation without direct manipulation by the operator, according to the manufacturer.[15]

Studies have demonstrated the negative effects of trying to condense RBC material into cavity preparations. Chadwick et al compared the effect of resin placement techniques (condensation versus smearing) on strength and porosity of RBCs.[16] While there was no significant difference in the total number of porosities, the condensation method yielded porosities of significantly larger diameter, which resulted in weaker compressive strength. It was concluded that handling of the resin should be minimized to reduce operator-incorporated voids. Opdam et al compared packable and syringed RBC for porosities and voids in Class I restorations.[17] Light microscopy was used to detect voids in vertical sections of prepared teeth. It was concluded that the syringe technique resulted in better adaptation and fewer voids. Elbishari et al used µCT analysis to demonstrate that the increase in size of resin particles and fillers was directly related to the size and number of voids.[18] In 2014, Park & Kim used µCT to quantify polymerization shrinkage in different RBCs and evaluate the internal adaptation of the composite to the tooth surface.[19]

The purpose of the present investigation was to evaluate the difference between conventional, hand-placed, incremental application of a standard hybrid RBC and sonicated application of a bulk-fill RBC in box-type and cylindrical cavity preparations.

Table 1. Percentage of porosity of the 4 main groups (n = 10).

Application	Shape	Porosity (%) Mean	SD
Bulk	Cylinder	1.42[a]	0.32
Incremental	Cylinder	2.87[b]	0.47
Bulk	Cube	3.12[b]	0.48
Incremental	Cube	5.16[c]	0.46

Analysis of variance revealed significant differences (α = 0.05; $P < 0.001$); Tukey post hoc test was used to detect where differences occurred. Means with the same superscript letters are not significantly different from each other.

Table 2. Percentage of porosity in subgroups (n = 10) of restoration shape (cube vs cylinder) and application method (bulk vs incremental).

Combined subgroup	Porosity (%) Mean	SD
Cylinder	2.00[a]	0.58
Bulk	2.97[b]	0.61
Incremental	3.87[b]	1.39
Cube	5.24[c]	0.74

Analysis of variance revealed significant differences (α = 0.05; $P < 0.001$); Tukey post hoc test was used to determine where differences occurred. Means with the same superscript letters are not significantly different from each other.

Materials and methods

This study used μCT to nondestructively characterize and quantify voids created during the placement of composite restorations using either traditional incremental placement with a hybrid RBC material with an average particle size of 0.4 μm (Kerr Point 4 Optimized Particle Composite System, Kerr Corporation) or a sonicated delivery system with bulk-fill composite technology (SonicFill Bulk-Fill, Kerr Corporation). Experimental restorations were fabricated using polytetrafluoroethylene molds of box-type (5-walled) or cylindrical preparations, simulating the adaptation of the composite materials to tooth preparations with line angles or without internal line angles, respectively. Both restoration types had consistent widths (5 mm) and depths (5 mm), which represented the maximum suggested depth of cure for the bulk-fill composite method.

For the bulk-filled specimens, a single compule of SonicFill Bulk-Fill composite was dispensed to a thickness of 5 mm using the SonicFill handpiece at a speed setting of 4. The manufacturer's recommended increment size for the conventional hybrid material is 2 mm. After the first increment was placed by syringe and smeared into place with a hand instrument, the composite was photopolymerized with a light-curing unit (Valo, Ultradent Products, Inc) for 20 seconds. The second 2-mm increment was placed and photopolymerized for 20 seconds. The final increment of 1 mm was similarly light cured. The light-curing unit was measured for a minimum output of at least 800 mW/cm^2 with a radiometer (Demetron LED, Kerr Corporation).

Ten simulated restorations were fabricated for each combination of shape and material: cube-shaped with bulk fill, cube-shaped with incremental fill, cylindrical with bulk fill, and cylindrical with incremental fill. The specimens were placed in water at 37°C for 24 hours prior to scanning.

Microfocus X-ray CT (SkyScan 1172, Bruker microCT) was used to analyze the specimens. The specimens were scanned 180 degrees with a 0.7-degree rotational increment using a source voltage and current of 70 kV and 141 μA with a 0.5-mm Al filter and a 9.5-μm image-pixel size, for a total of 524 × 1000 pixels per slice. The scanned images were reconstructed into 3-dimensional images using NRecon software (Bruker microCT), and the voids were analyzed and measured using CTAn software (Bruker microCT) for percentage and total volume of porosity as well as number of actual pores. All of the measurements were made by scanning the same volume of interest, measuring 72.6 mm^3, to allow standardized comparisons. The area of the standardized scan included all bound surfaces of the restoration.

Analysis of variance (ANOVA) was performed to detect a statistical difference among the 4 groups. If a significant difference was found, Tukey post hoc tests were performed to determine where differences occurred. A significance level of 0.05 was used for all analyses.

Results

The percentages of porosity of the 4 main groups are summarized in Table 1. An ANOVA indicated that there was a statistically significant difference in porosity among the 4 main groups ($P < 0.001$). A Tukey post hoc test was used to detect where differences occurred. Sonicated bulk-filled composite restorations with a cylindrical shape demonstrated the least amount of total porosity (1.42%). This group was significantly different from the other 3 groups. Cylindrical hybrid composite placed in 3 increments yielded the next lowest porosity (2.87%). Cube-shaped, sonicated bulk-filled composite restorations demonstrated a mean porosity of 3.12%. The aforementioned 2 groups were not significantly different from each other. The most porosity (5.16%) was seen in the cube-shaped, hybrid composite restorations that had been placed incrementally. This group was significantly more porous than the other 3 groups.

When the groups were subcategorized into the specific characteristics of shape type (cube vs cylinder) and application method (bulk vs incremental), some interesting observations were noted (Table 2). To test the importance of restoration shape versus application method on the porosity of the restoration, an ANOVA was performed. A Tukey post hoc test revealed where differences occurred. The cylindrical group, which included both bulk-filled and incrementally placed specimens, demonstrated the least amount of porosity (2.00%), significantly less than the other 3 subgroups. The bulk-filled group, which included both cylindrical and cube-shaped specimens, was found to have a porosity of 2.97%, and the incrementally placed specimens, which included both cylinders and cubes, had 3.87% porosity. These 2 groups were not statistically different from each other. The greatest amount of porosity was seen in the cube-shaped group (5.24%), which included both bulk-filled and cylindrical specimens. The cube-shaped group was found to be statistically different from the other subgroups.

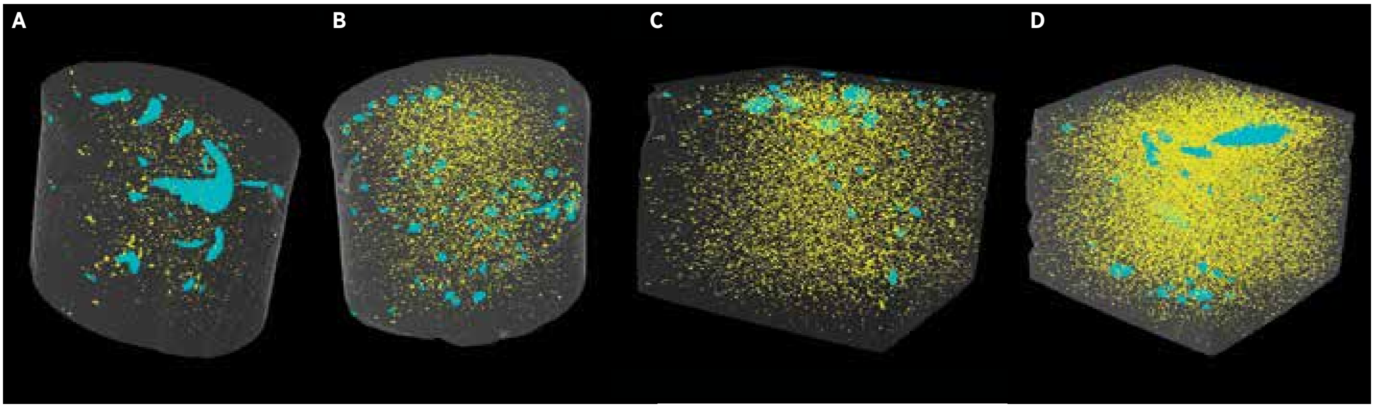

Figure. Reconstructed microcomputed tomograms. Yellow indicates voids less than 100 µm in diameter. Blue indicates voids between 100 and 500 µm in diameter. A. Sonicated bulk-filled cylinder (1.42% porosity). B. Hybrid incrementally filled cylinder (2.87% porosity). C. Sonicated bulk-filled cube (3.12% porosity). D. Hybrid incrementally filled cube (5.16% porosity).

Discussion

Microcomputed tomography is relatively new to dental research, but its potential is enormous. It has been applied in the measurement of enamel thickness, root canal morphology and preparation, micro–finite element modeling, dental tissue engineering, and mineral density.[20] It has also been used to evaluate the internal adaptation of restorations.[21,22] X-rays from a µCT pass through the specimen in a single plane along the entire interface as a 2-dimensional image. Numerous 2-dimensional image slices are then processed into 3-dimensional reconstructions for interpretation.

Several recent studies have used µCT techniques to nondestructively evaluate polymerization shrinkage and marginal integrity and adaptation.[23-27] Very few studies have used µCT in an attempt to quantify porosity or voids in dental materials. The authors of the present study conducted a computerized search by using electronic databases—MEDLINE on OvidSP, PubMed, Web of Science (Thomson Reuters), Scopus (Elsevier), and Google Scholar—from their inception to the end of the first week of December 2014. The specific search terms "((voids) AND((composite resin)AND micro ct))" yielded only 8 studies.

The current study used µCT to nondestructively evaluate the porosity of a sonicated bulk-filled RBC and a standard, nonflowable microhybrid RBC (Figure). Additionally, the study incorporated the variable of restoration shape: cube-shaped or cylindrical. The group with the least amount of porosity was found to be the combination of a sonicated bulk-filled composite with a cylindrical shape (1.42%). The least desirable combination was the microhybrid RBC placed incrementally into a cube shape (5.16%). The range of porosity is in agreement with those of other published studies.[18]

When groups were divided by shape (cube or cylinder) and application method (bulk-filled or incrementally placed) and subjected to ANOVA, significant differences were also found. Specimens that were cylindrical, regardless of whether they were bulk filled or incrementally placed, demonstrated the least amount of porosity (2.00%). Cube-shaped specimens, regardless of whether they were bulk filled or incrementally placed, demonstrated the most porosity (5.24%).

These findings may lead to a very important shift in the way operators think about dental materials. The results of the current study should remind dentists that the physical properties of a dental material are also dependent on extrinsic factors. A specific parameter—in this case, porosity of the restorative material—is usually thought of as an inherent property of the material itself and very little attention is paid to other extrinsic details that could change the performance of the intrinsic parameter. For example, line angles inside tooth preparations are well-known stress concentrators. These internal line angles and corners also make it much more difficult to deliver a viscous substance such as RBC into the tooth preparation. In an attempt to circumvent these issues, flowable composites and composite heating/warming devices were introduced to the dental products market.[28] Intimate adaptation of the restorative material to the cavity preparation has been a major concern, especially with materials that do not pack well.

Considering the main reasons for RBC failure, the most important mechanical properties to evaluate in dental materials are most likely fracture toughness, fatigue resistance, and wear. All restorative materials will contain flaws; therefore, fracture toughness may be the most critical factor in determining resistance to intraoral fracture.[29] Voids in a restorative material are flaws; thus they will contribute to making the material more prone to fracture. Every attempt should be made to ensure that factors within the control of the operator are managed to minimize the porosity within the restoration and adapt the material intimately to the cavity walls. The results of the current study suggest that sonication of a bulk-filled composite and adaptation of tooth preparations to avoid sharp internal line angles will provide the best opportunity to minimize voids within RBC restorations.

Conclusion

Within the parameters of this study, RBC restorations that were applied to cylindrical cavities using a sonicated bulk-filled application method produced the least amount of porosity. Restorations that were incrementally placed into cube-shaped cavities produced the greatest amount of porosity.

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