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Effect of Sonic Resin Composite Delivery on Void Formation Assessed by Micro-computed Tomography

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Clinical Relevance

Voids in resin composite restorations may be generated during restorative procedures, leading to a reduction in mechanical, physical, and biological properties. A sonic delivery method may lead to a higher incorporation of air within the restoration and, consequently, higher void formation.

SUMMARY

Objectives: The aim of this study was to quantify the internal void volume formation in commercially available, resin composites inserted using conventional or sonic insertion methods, and analyzed using three-dimensional (3D) micro-computed tomography (μCT).

Methods and Materials: Four resin composites were evaluated: one conventional (Herculite, Ultra, Kerr Corporation, Orange, CA, USA), one flowable bulk fill (SureFil SDR Flow, Dentsply International, York, PA, USA), and two packable bulk fill (SonicFill, Kerr Corporation, and Tetric EvoCeram Bulk Fill, Ivoclar Vivadent Inc, Schaan, Liechtenstein). Eight groups were evaluated according to each resin composite type and insertion method (conventional or sonic; n=5). Forty ABS 3D-printed cylindrical molds, 5.0 mm in diameter and 4.0 mm in depth, were fabricated. For the conven-

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tional resin composite, the mold was filled incrementally (two layers), while for bulk-fill resin composites, insertion was performed in a single increment. The sonic insertion method was performed using a specific handpiece (SonicFill Handpiece, Kerr Corporation). Resin composites were light cured using a multipeak light-emitting diode light-curing unit (VALO, Ultradent Products Inc, South Jordan, UT, USA) in its regular mode. Samples were evaluated by μCT, and data were imported into software (Amira, version 5.5.2, VSG, Burlington, MA, USA) for 3D reconstruction, from which the percentage of void volume was calculated. Data were analyzed using two-way analysis of variance and Tukey post hoc test at a preset alpha of 0.05.

Results: The conventional insertion method resulted in reduced porosity, compared with sonic insertion, for SureFil SDR Flow and Tetric EvoCeram bulk fill. The sonic insertion method did not demonstrate any influence on void formation for Herculite Ultra or SonicFill.

Conclusion: Results suggest that the sonic insertion method might increase void formation during resin composite delivery, depending on restorative material brand.

INTRODUCTION

The number of resin composite posterior restoration procedures has greatly increased, due to higher esthetic demands from patients and legal constraints of amalgam use within many countries.[1] A multitude of factors affect the clinical outcome of resin composite restorations, such as quality of the polymerization process,[2] mechanical properties,[3] and insertion technique.[4]

For decades, the incremental (or layering) technique has been the most common insertion method for resin composite, in an attempt to reduce the effects of polymerization shrinkage and stress.[5] The polymerization reaction results in a volumetric reduction caused by formation of covalent bonds established between monomers, which may lead to stress at the tooth/restoration interface, resulting in inadequate adaptation, micro-cracking, postoperative sensitivity, marginal staining, and secondary caries.[5] By placing small resin composite increment thickness (up to 2.0 mm), a reduction in gap formation between the restoration and preparation walls has been observed.[6] In addition, improved optical properties and esthetic outcomes may be achieved by using different composite shades, opacities, translucencies, and a variety of layering techniques.[7]

Bulk-fill resin composites have recently been introduced for insertion into a preparation using one single increment, followed by one light-curing exposure.[8] The main advantages of these products are stated to be lower volumetric shrinkage and shrinkage stress when compared with conventional, methacrylate-based materials[9] and also less chair-side time. A specific sonic handpiece has been developed, in combination with a bulk-fill resin composite (high inorganic content, regular consistency), to improve material adaptation into a preparation. It is thought that the sonication method imparts energy into the material, changing its rheological properties, decreasing viscosity, and leading to enhanced adaptation between resin composite and preparation surfaces, while maintaining mechanical properties similar to those of a hybrid resin composite.[10]

Incorporation of air bubbles and voids in resin composite restorations is an area of concern to all clinicians. The presence of voids may be influenced by material manipulation failures during product manufacturing and packaging, filler size and content, and high-viscosity monomer use, among others.[11-16] An increased amount of voids could result in increased water sorption and, consequently, increased staining.[17] Also, these defects are potential loci of stress concentration and may act as initiation points for fracture and crack propagation, reducing mechanical strength and wear resistance.[17] Voids at the adhesive interface reduce bond strength between composite and an adhesive system, by reducing the total bonded surface area.[18] In addition, higher bacteria retention and biofilm formation could result from voids on the restoration surface.[19]

Void formation has been evaluated by sectioning samples, followed by observation and quantification using a light microscope.[15,20] This process is destructive, tedious, and time-consuming and does not provide quantification of the entire restoration mass. Micro-computed tomography (μCT) analysis has been used for bulk volumetric evaluations (using x-ray scanning), generating 3D rendering and spatial quantification of materials.[21] Thus, this method is proven to be a suitable tool for porosity assessment inside of resin composite restorations.[13,22,23]

The purpose of this study was to quantify porosity within resin composites (regular and bulk-fill) that were placed using either conventional or sonic

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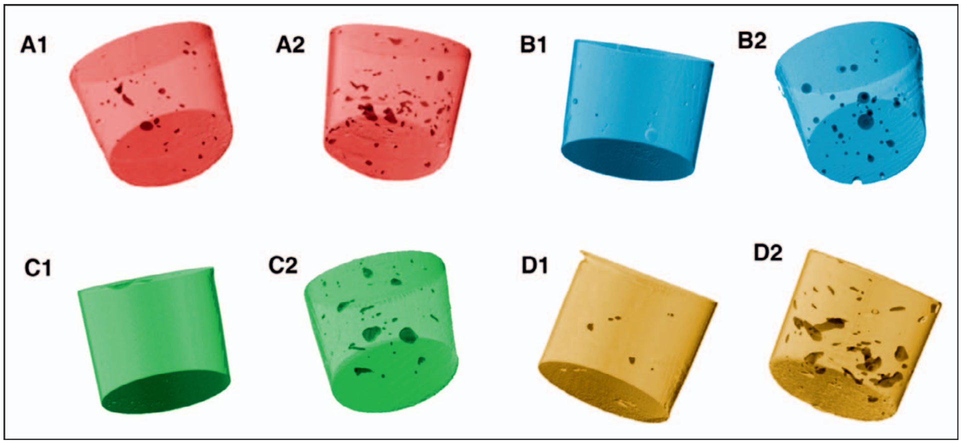

Figure 1. *3D rendering of one representative sample of each composite showing presence of inner voids. A1- Herculite Ultra using conventional insertion method; A2- Herculite Ultra using sonic insertion method; B1- SureFil SDR Flow using conventional insertion method; A2- SureFil SDR Flow using sonic insertion method; C1- Tetric EvoCeram Bulk Fill using conventional insertion method; C2- Tetric EvoCeram Bulk Fill using sonic insertion method; D1- SonicFill using conventional insertion method; D2- SonicFill using sonic insertion method.*

insertion methods and analyzed using μCT technology. The hypothesis tested was that the sonication insertion method would reduce resin composite void formation compared with a conventional placement method.

METHODS AND MATERIALS

Specimen Preparation

Cylindrical molds were three-dimensionally (3D) printed using a white, thermoplastic polymer (acrylonitrile butadiene styrene [ABS], Octave Systems Inc, Santa Clara, CA, USA) having a 4.5-mm internal diameter and a height of 4.0 mm (Figure 1). The internal walls were standardized by using a standard 5-mm drill bit, resulting in parallel, uniform surfaces. A polyester strip (Mylar Type D, 0.08 in., DuPont, Wilmington, DE, USA) was placed under the mold, prior to resin composite placement. Four different resin composites were used (Table 1). Each material was inserted into the molds using two different methods: conventional (according to the manufacturer's instructions) and by extrusion through a sonic delivery instrument (SonicFill Handpiece, speed level 3, Kerr Corporation, Orange, CA, USA).

To fabricate each specimen, one resin composite compule was used. For the sonic insertion method, resin composite material was transferred from each original compule into a SonicFill compule (compatible with the SonicFill Handpiece). The SonicFill compule is unique in that it can be dismantled and reassembled. A SonicFill compule was dismantled, the content was emptied, and the compule form was rinsed and immersed in acetone followed by ultrasonic agitation, to remove any composite residue. Afterward, the curved tip of each evaluated composite compule was removed by using a heavy-duty cutter, and the resin composite content was extruded into one of the previously prepared, empty SonicFill compules, followed by replacement of the piston. All procedures were performed in a light- and temperature-controlled room. Conventional placement consisted of directly extruding the material into the mold from the supplied resin composite delivery device. The plastic mold was filled from bottom to top, followed by vertical pressure, using a metallic spatula (AECRJ2XP, American Eagle, Missoula, MT, USA). A piece of polyester strip was then placed

Table 1: *Restorative Materials Used*

Material	Manufacturer	Shade	Organic Composition[a]	Inorganic Composition[a]	Lot No.
Herculite Ultra	Kerr Corporation	A2	Bis-GMA, TEGDMA, Bis-EMA	SiO_2 glass, oxide (78%wt)	5123035
SureFil SDR Flow	Dentsply International	U	Modified UDMA, TEGDMA, EBPDMA	Ba-Al-F-B-Si glass and Sr-Al-F-Si glass (68%wt)	0511
Tetric EvoCeram Bulk Fill	Ivoclar Vivadent, Inc	IVA	Bis-GMA, Bis-EMA, UDMA	Ba-Al-Si glass, prepolymer filler (monomer, glass filler, and ytterbium trifluoride), spherical mixed oxide (79-81%wt)	S38401
SonicFill	Kerr Corporation	A2	Bis-GMA, TEGDMA, EBPDMA	SiO_2 glass, oxide (83.5%wt)	5135439

Abbreviations: Bis-GMA, bisphenol A glycidyl methacrylate; TEGDMA, triethyleneglycol dimethacrylate; Bis-EMA, ethoxylated bisphenol A dimethacrylate; UDMA, urethane dimethacrylate; EBPDMA, ethoxylated bisphenol A dimethacrylate.
[a] *Composition information obtained from the manufacturer.*

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on the top surface and slightly pressed flat, using a microscope glass slide (Gold Seal, Becton Dickinson and Company, Franklin Lakes, NJ, USA). For the sonic insertion method, sonication was generated by a handpiece attached to a high-speed multiflex connection,[24] and all resin composites were inserted in a single increment ("bulk filled"), with the exception of Herculite Ultra (Kerr Corporation), which was inserted using two separate, 2.0-mm-thick increments, as recommended by the manufacturer. Samples were light cured, using a characterized multiwave (400 nm, 440 nm, and 460 nm) light-emitting diode (LED) light-curing unit (VALO, Ultradent Products Inc, South Jordan, UT, USA), for 40 seconds (n=5), in its regular output mode (1521.2 ± 9.2 mW/cm^2). The distal end of the curing tip was in contact with the polyester sheet during photopolymerization.

μCT Analysis

Each polymerized specimen was scanned using a μCT instrument (μCT40, Scanco Medical, AG, Basserdorf, Switzerland), calibrated using a phantom standard, at 70 KVp/BH 200 mgHA/ccm. Five specimens at a time were placed in the sample holder. The instrument was operated at medium resolution (16 μm/slice) using 70 kVp (114 μA) resulting in approximately 380 slices per sample. Data were analyzed using software (Amira, version 5.5.2, VSG, Burlington, MA, USA). A similar, virtual cylindrical shape was then designed, having the same specimen measurements (5.0 mm in diameter and 4.0 mm height), and its cylinder volume was calculated using the "Material Statistics" software function. Images obtained from samples were subjected to the "Boolean" function, to subtract the mold from the analysis. Using the calculated ideal cylinder volume, image data were cropped to obtain similar cylindrical volumes for analysis. The inner resin composite void volume was calculated using the "Threshold" function, to separate voids from resin composite, and the "Material Statistics" software function determined porosity for each specimen. Using these values, the volume of voids was calculated as a percentage of the total volume of resin composite. Data were analyzed using a two-way analysis of variance (ANOVA) and Tukey post hoc test (IBM SPSS, 22, Armonk, NY, and Chicago, IL), at a preset alpha of 0.05.

RESULTS

Table 2 presents the means and standard deviations of void volumes (in percentages) for each material, as a function of insertion method (regular and sonic). Preliminary analysis of data showed heterogeneous variances between groups. Analyses that homogenized the variances led to similar conclusions to the unadjusted analysis that is presented. The two-way ANOVA indicated that the factors "material" (p=0.002) and "placement technique" (p<0.001) significantly influenced results. The ANOVA also detected a significant interaction between the major factors (p=0.002). The analysis indicated sufficient power for the interaction term (94%).

Table 2: *Mean (SD) Void Volume (%) for Each Composite and Insertion Method*[a]

Material	Insertion Method	
	Conventional	Sonic
Herculite Ultra	1.93 (1.14) Aa	2.53 (0.52) Ba
SureFil SDR Flow	1.64 (0.75) Ab	7.08 (3.72) Aa
Tetric EvoCeram Bulk Fill	0.71 (0.50) Bb	2.55 (0.68) Ba
SonicFill	2.43 (0.36) Aa	2.76 (0.95) Ba

[a] *n=5 specimens per experimental group. Means followed by similar letters (lowercase letters compare insertion method for each material and uppercase letters compare material for each insertion method) are not statistically different (p>0.05).*

SonicFill and Herculite ultra resin composites demonstrated significantly higher void percentage compared with Tetric EvoCeram Bulk Fill and Surefil SDR Flow, when using the conventional insertion method (p=0.0217). However, when using the sonic device, SureFil SDR Flow showed significantly increased void volume compared with that of Herculite Ultra, SonicFill, and Tetric EvoCeram bulk fill (p=0.0065).

Sonication had no significant effect on void volume percentage for Herculite Ultra and SonicFill resin composites, but significantly increased void percentages were observed for SureFil SDR Flow and Tetric EvoCeram bulk fill. Qualitative 3D image analysis of internal void formation showed an increase in void volume for all materials sonically inserted (Figure 1).

DISCUSSION

The sonic insertion method is an alternative to manual extrusion and placement of resin composite. In theory, resin composite sonication would facilitate insertion and increase marginal and internal adaptation, because of a decrease in the material's viscosity, while maintaining original composition and physicochemical properties. The research hypothesis was rejected, because the sonic insertion method resulted in significantly higher void volume for some resin composites, compared with the use of

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a conventional insertion method for the same material. An increased void formation may be associated with changes in resin composite rheological properties (reduced viscosity under sonication) from that originally provided by the manufacturers. Sonication tended to increase void formation for some materials evaluated, but not for others, as observed in quantitative and qualitative analyses (Table 2; Figure 1).

Such increased void formation was more evident for the two bulk-fill resin composites evaluated, which were specifically formulated to be applied as a single increment. Bulk-fill resin composites are relatively new materials that usually demonstrate lower volumetric shrinkage,[9] even when applied in 4.0- to 5.0-mm increment thicknesses.[8] The use of these resin composites tends to simplify restorative procedures, reducing chairside time and requiring less manipulation for each increment, which would lead to fewer flaws, as confirmed by this study. Currently, the bulk-fill resin composite SonicFill is the only material recommended by the manufacturer for use with the SonicFill Handpiece. For this material, the sonic insertion method did not significantly increase void volume. Even though the void volume of SonicFill was not significantly changed as a result of the different insertion methods, its void value was still fairly high. Because this material is designed specifically to be dispensed by the sonic handpiece, it seems reasonable that manufacturers could control the innate void volume of the product. In so doing, a denser and less pitted polished surface might be produced, providing enhanced potential for restoration longevity and greater esthetics.[25] Lower mechanical properties have been reported for SonicFill resin composite, when used in association with a sonic handpiece, compared with use of a conventional insertion method.[26]

Use of μCT analysis provided an accurate measurement of the total internal void volume, without the need of destructive sectioning and polishing, usually required for traditional methods.[9,21,23] The 3D rendering allowed void visualization within the intact restorative materials and also provided quantitative measurements.[13] As noted previously, the presence of internal and surface-formed voids can drastically affect restoration properties and appearance. Voids located at tooth-restorative material interfaces may lead to marginal staining and reduced bond strength.[18] In addition, porosity potentially leads to crack formation and consequently to bulk failure.

The conventional insertion method demonstrated a more homogeneous structure for SureFil SDR Flow and Tetric EvoCeram bulk fill compared with that of SonicFill and Herculite Ultra (the latter applied in two separate increments). The conventional layering technique used for the regular resin composite (Herculite Ultra) proved to increase the volume of voids as compared with a flowable, bulk-fill resin composite (SureFil SDR Flow) and high-viscosity, bulk-fill resin composite (Tetric EvoCeram Bulk Fill). Previous studies using high-resolution tomography also detected porosities inside resin composite restorations, reporting detrimental effects of layering application, in terms of porosity.[13,23] These results corroborate with another study, in which the prolonged packing time had a negative effect on the resin composite surface hardness, and conversely, increased mechanical properties were obtained by placing the material in small increments.[4]

In the present study, the lowest void formation was observed using Tetric EvoCeram bulk fill (which is a high-viscosity, bulk-fill resin composite) when applied without sonication. Similar results were observed in another study that reported less porosity with higher-viscosity resins.[13] A reduction in resin composite viscosity, in conjunction with the vibration generated by the sonic handpiece, may lead to a higher incorporation of air within the restoration, which was observed for Surefil SDR Flow, resulting in a high standard deviation. Because of the reduced viscosity of the material (the only flowable composite evaluated), void formation was increased and unpredictable. In addition, the sonication process may cause smaller, isolated bubbles (already present in the material) to coalesce and form a consolidated, large bubble, now termed a *void*. When resin composite recovers its original rheological properties, the entrapped air is more obvious and potentially has a greater effect on the bulk material properties.

The void volume measured in the current work was calculated based on an ideal cylindrical designed in the software. Thus, the void formation was limited to the cylinder volume and did not take into consideration the void formation on the walls of a preparation. Also, only SonicFill compules were used for all the materials, because the respective compule for each material was not compatible with the SonicFill handpiece. Furthermore, only one frequency of sonication was evaluated (SonicFill handpiece), and further studies should be conducted to evaluate the effect of different frequencies and different resin composite formulations on the

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potential for void formation. The influence of these voids on mechanical properties of bulk-fill restorations and their clinical implications should be evaluated as well.

CONCLUSIONS

Within the restrictions imposed by the experimental methods used, the following conclusions may be made:

1. There was no significant difference in void volume of SonicFill restorative material when using either the sonic or conventional, manual method of placement.
2. The void volumes of other bulk-fill resin composites (a flowable and a high-viscosity paste) were significantly increased when using the sonic insertion method.
3. Sonic insertion of a 2.0-mm-thick increment of conventional resin composite did not significantly change void volume compared with placement using conventional, manual methods.

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Conflict of Interest

The authors certify that they 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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