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Bulk Fill vs. Incremental Fill: Does it matter? An investigation into porosity and flexural strength of composite resins

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Abstract

Bulk fill composites not only offer clinicians a less technique sensitive placement method of direct composite restorations, but also may offer the advantage of lower porosity due to the bulk placement of material. The purposes of this study are threefold: (1) to nondestructively compare the porosities of a conventional, nanofilled resin-based composite (RBC) with bulk-fill and bulk-fill-flowable RBCs using micro-computed tomography (μ CT) analysis, (2) to investigate whether incremental and bulk-fill techniques can affect the internal porosities of a restoration, generating void disparities between restorations, and (3) to explore whether the strength of a restoration is related to its internal porosities or voids. 162 specimens were created by injecting the restorative material into stainless steel molds until completely filled using either a bulk fill (filled in one step) or incremental fill (filled in 2 increments). Each sample was then scanned using MicroCT in the middle 5mm of the sample to analyze the porosity and subjected to a 3 point bend test to calculate flexural strength. The combination that yielded the lowest porosity was the Filtek Supreme Ultra incrementally filled (FSU – inc.) (0.19%) while the combination that yielded the highest porosity was the Filtek Bulk fill flowable - incrementally filled (FBFF – inc.) (0.33%). Filtek One – bulk filled (F1-B) yielded the highest strength (137.27 MPa), while Filtek Bulk Fill Flowable – bulk filled (FBFF-B) yielded the lowest results (80.08 MPa). A 2-way ANOVA analysis revealed that overall the bulk fill samples had a higher flexural strength while there was no significant difference between porosities of bulk fill and incremental fill groups. RBC restorations that were placed using a bulk fill technique produced a higher flexural strength than those filled by incremental fill despite having a slightly higher porosity.

Introduction

In recent years, new composite systems using bulk-fill technology have emerged. These RBCs allow clinicians to layer in 4-5mm increments instead of 1-2mm increments, which reduced technique sensitivity and thereby simplified and accelerated the placement of large posterior RBC restorations.¹ These new bulk-fill systems claim to have better marginal integrity/internal adaptation, and lower polymerization shrinkage than conventional RBCs.²

Van Dijken (2015) determined that after three years there was no significant statistical difference between annual failure rates of a bulk fill composite and a conventional composite³. In 2018 Heck et al. found the same findings with a 10 year Randomized Controlled Trial (RCT) between a bulk fill and a conventional composite.⁴ Despite a low annual failure rate of 1.2% for class I and class II bulk-fill restorations,³ researchers continue to be concerned about polymerization shrinkage, marginal leakage, accelerated wear, and fatigue degradation of bulk-fill RBCs.⁵

However, one current challenge, which is frequently overlooked, is the porosity of the dental composite restoration. Voids in the material may cause marginal leakage, discoloration, increased wear, strength degradation, and incomplete adhesion at the resin and tooth interface.⁴

Since the inception of dental composite restorations, researchers have been investigating the best and most efficient way to place dental composite restorations. The open sandwich technique was developed in 1977 to create posterior composites with better marginal adaptation and fewer voids.⁶ Chadwick et al (1989) compared placement techniques (packing vs smearing) with compressive strength. He found that the two techniques, although having similar number of voids, the packing technique had considerably larger voids. These voids decreased the compressive strength of the material.⁷ Opdam et al (2002) determined that syringed RBC created fewer voids than packable composites.⁸

Elbishari et al (2012) used μ CT to compare the filler size with both fracture toughness and voids. Their results showed that the filler size had a strong positive correlation to void percentage, but that filler size had no effect on fracture toughness. This can be explained by the fact that fracture toughness is not affected by variations in filler size or distribution.⁹ Jarisch et al. (2016) compared the porosity of sonicated bulk-fill RBCs with that of a traditional composite. Their findings showed that restorations placed using a bulk-fill technique yielded less porosity than those of an incremental technique.⁴

The layering technique has the risk of incorporating air or contamination between the layers.³ This was demonstrated by Soares et al (2017) where they showed that bulk fill composites had a statistically less voids as measured through radiodensity than incrementally filled restorations. "Future microcomputed tomography studies should be performed to detect the void location and volume and to correlate this occurrence with the mechanical performance of the bulk and incremental filling technique."¹⁰

Over the past several years μ CT has been used to evaluate multiple aspects and characteristics/properties of resin composite restorations. It has been used to compare 3D shrinkage vectors,¹¹ internal adaptation,^{12, 13, 14, 15} presence of voids¹⁶, Polymerization shrinkage,^{17, 18, 19} marginal adaptation²⁰ and microleakage.²¹ Hirata et al. used μ CT to show the effects of using several different bulk fill RBCs using a sonicated handpiece. His evidence showed that using these composites with the sonicated handpiece creates more voids and larger voids compared to a conventional or manual technique.²²

Roberts et al. (2020) conducted an in vitro study of the use of bulk fill composite core materials. They found that porosity varied amongst the many materials tested. One of the limits discussed in their study was the resolution on the μ CT for larger samples such as those which he was using had to be lowered in order to encompass the entire sample.²³ Similar results were found by Demirel et al. (2019) They researched the porosity of different bulk fill composites against a conventional flowable composite control and determined that Filtek One had statistically significant lower percentage of void volume than other flowable composites.²⁴

Theoretically, the more porosity is in a restoration, the lower is its strength. There is limited research and/or evidence in the understandings of how the strength of a restoration is related to its internal porosities or voids. The purposes of this study are threefold: (1) to nondestructively compare the porosities of a conventional, nanofilled resin-based composite (RBC) with bulk-fill and bulk-fill-flowable RBCs using microtomographic (μ CT) analysis, (2) to investigate whether incremental and bulk-fill techniques can affect the internal porosities of a restoration, generating void disparities between restorations, and (3) to explore whether the strength of a restoration is related to its internal porosities or voids.

The null hypotheses to be tested:

- 1) The internal porosity of a conventional, nanofilled RBC is equivalent to bulk-fill and bulk-fill-flowable RBCs, regardless of the material is being placed using a bulk-fill technique or an incremental technique.
- 2) Bulk-fill technique produces equivalent porosity and strength in comparison with incremental technique.
- 3) There is no relationship between the strength of a material and its porosities.

Materials and Methods

Figure 1

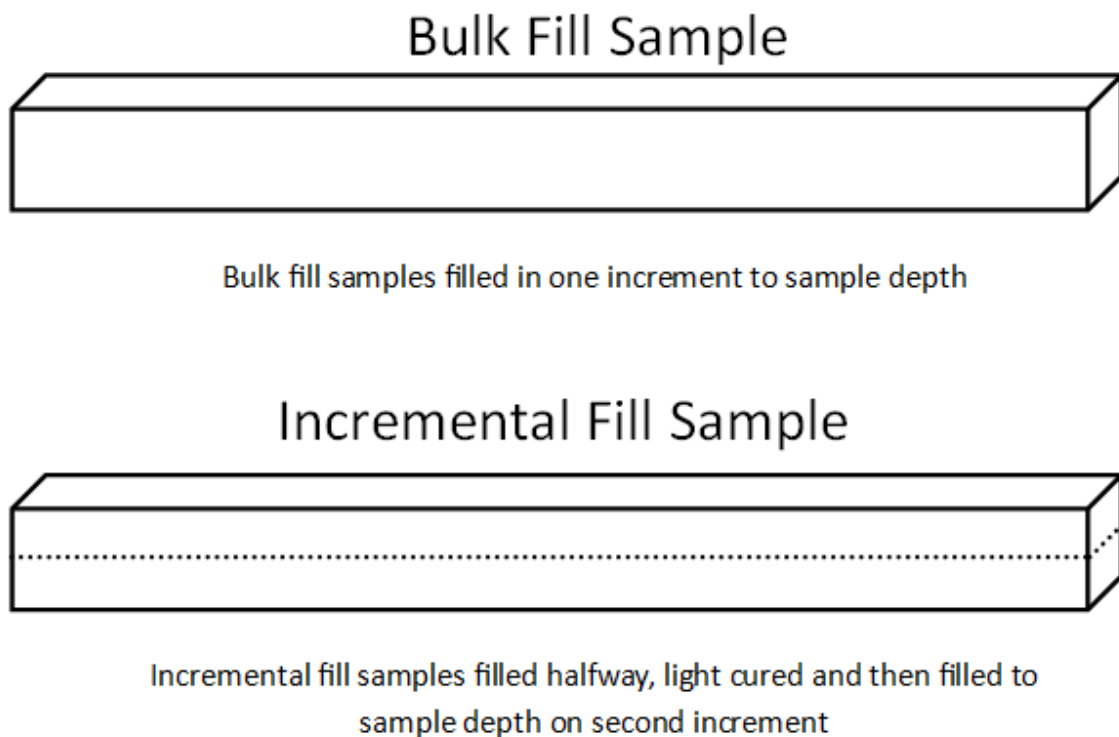


Figure 1 demonstrates the difference between the filling techniques of the bulk fill vs the incremental fill groups. Three different stainless steel (SS) molds, having dimensions (HxWxL) of 2x2x25, 3x2x25, and 4x2x25 mm³, were used. For the bulk fill groups, a SS mold with 2x2x25 mm³

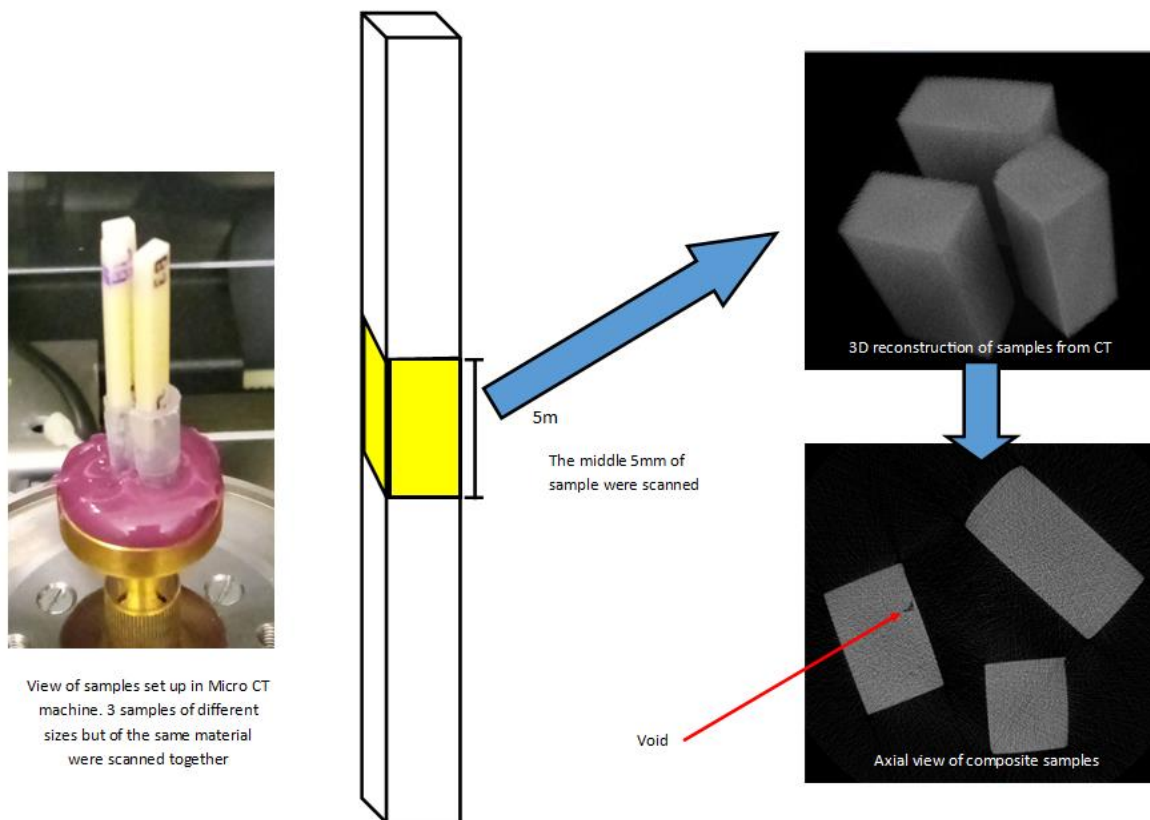
was placed on a plastic strip-covered glass slide to fabricate a 2x2x25 mm³ sample. The specimens were created by injecting the restorative material into the mold until completely filled. The top surface of the mold was covered with a second plastic strip and glass slide. The top side of the specimen was exposed to a light polymerization unit in 3 separate overlapping increments of 60 seconds each. Next, the mold was turned, and the opposite side of the specimen was exposed to the light in a similar manner. The specimens were then removed from the mold and stored in distilled water at an intraoral temperature of 37°C for 24 hours. These aforementioned steps were repeated to fabricate specimens of 3x2x25 and 4x2x25 mm³ dimensions.

For the incremental fill groups, the mold was filled half of the way up with material (as indicated by a dashed line in figure 1). Samples were light cured (top side only) as described before, then a second increment was added to finish filling the mold and light cured on both sides as described above. All samples were then removed from the molds and polished using Bueler CarbiMet™ grit 600 [P1200] sand paper until all excess material or flash was removed to form a beam shape.

Porosity

A novel microtomographic technique was used to evaluate the internal porosity of each flexural strength specimen. Eight specimens per group (18 groups) were scanned. Samples were placed in a microtomography unit (Sky Scan 1172 X-ray microtomograph, Bruker MicroCT [55kV – 181mA, 5.1µm, Al 0.5mm, 2000 x 1048 resolution]) and scans of the middle 5mm of the samples were made. Recorded images were then reconstructed (NRecon, version 1.4.4, Bruker MicroCT) into 3-dimensional images, which were analyzed using proprietary software (CT Analyzer, version 1.6.0.0, Bruker MicroCT) for percent porosity.

Figure 2



Density

Density of each sample was measured using a density scale (Torbal AGCN200, Torbal, Bohemia, NY, USA). Each sample was placed in the scale and compared to the buoyant weight in distilled water. Density was then calculated in g/cm³ using Archimedes' principle.

Flexural Strength

Each specimen was placed on a 3-point bending test device which is constructed with a 20 mm span length between the supporting rods. The central load was applied with a head diameter of 2 mm, and a crosshead speed of 0.5 mm/min using a universal testing machine (Instron, Norwood, MA, USA). The flexural strength (σ) was calculated using the equation:

$$\sigma = \frac{3Fl}{2bd^2}$$

Where F is the loading force at the fracture point, l is the length of the support span (20 mm), b is the width, and d is the depth. Measurements were made using an electronic digital caliper. Flexural modulus (E) was determined from the slope of the linear region of the load-deflection curve using analytical software (Instron, Norwood, MA, USA).

Statistical analysis

With 162 total samples, based on 8 per each composite type (3 brands), fill technique (bulk or incremental) and size (3 levels) combination, and letting $\alpha=0.05$ the study had 80% power to detect a 20% difference in flexural strength and porosity among composite types and sizes, and a 14% difference between bulk and incremental fill techniques. This assumed a coefficient of variation of 0.3 and used Tukey's honestly significant difference to account for multiple comparisons among the 3 composite types and 3 sizes.

A mean and standard deviation were determined per group. Data was analyzed through SASS with a 3-way ANOVA and Tukey's post hoc tests per test type ($\alpha = 0.05$). Linear regression analysis using a bivariate model was performed for correlation between porosity and flexural strength or flexural modulus.

Results

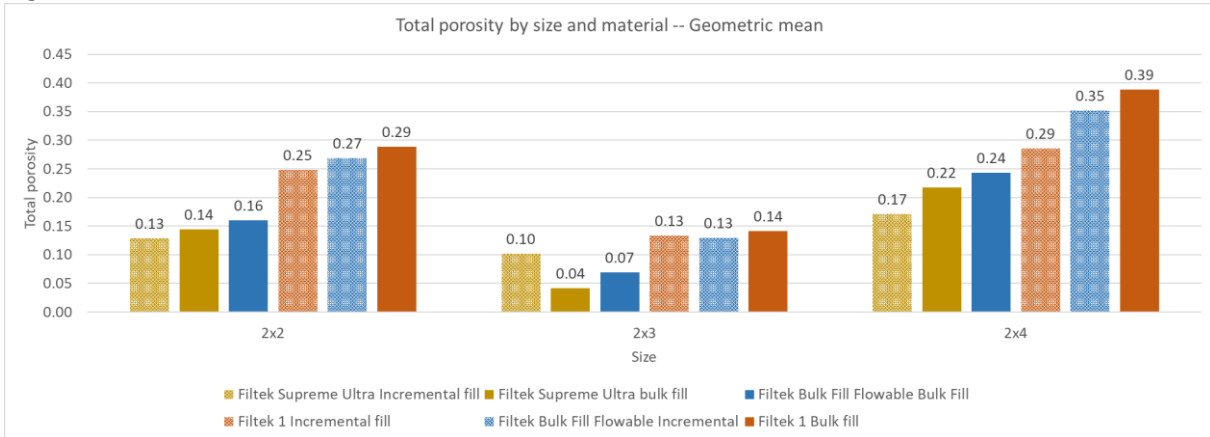
Table 1

Group	Porosity (%)		Flexural Strength (MPa)	
	Mean	SD	Mean	SD
Filtek One – Bulk Fill	0.32	0.24	137.27	24.68
Filtek Supreme Ultra – Bulk Fill	0.22	0.41	116.77	21.40
Filtek Bulk Fill Flowable – Bulk Fill	0.24	0.35	80.08	34.23
Filtek One – Incremental Fill	0.24	0.14	124.07	24.24
Filtek Supreme Ultra – Incremental Fill	0.19	0.24	108.37	27.52

Filtek Bulk Fill Flowable – Incremental Fill	0.33	0.29	85.69	30.57
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Porosity

Figure 3



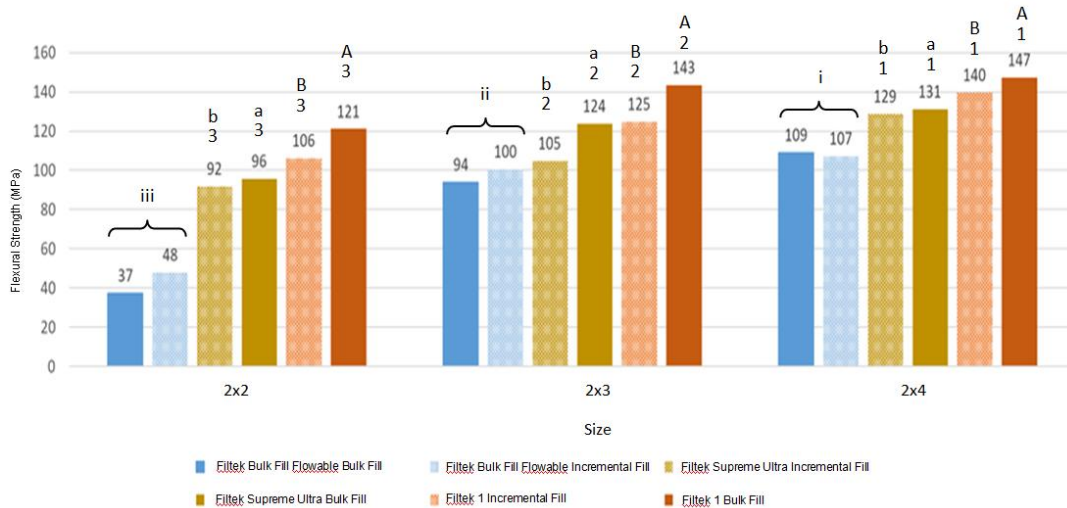
Caption figure 4: There was a statistically lower porosity of all the 2x3 groups compared to the 2x2 and 2x4 groups. Filtek 1 had a statistically higher porosity than Filtek Supreme ultra, but there was no significant difference between incremental fill and bulk fill groups for non-flow. For the flow group, however, the incremental fill groups had higher porosity than the bulk fill groups.

The percentages of porosity and average strength of the 6 main groups are summarized in Table 1. The combination that yielded the lowest porosity was the Filtek Supreme Ultra incrementally filled (0.19%) while the combination that yielded the highest porosity was the Filtek Bulk fill flowable - incrementally filled (0.33%).

A multifactor ANOVA test demonstrated that there was a statistically significant difference ($p < 0.001$) in porosity based on the brand of composite with the Filtek One having significantly more porosity regardless of filling technique. However, the type of fill (incremental vs bulk fill) had no significant difference ($p = .969$). The size of the sample made a statistically significant difference with the 2x3 samples having lower porosity than the other two sizes. Flowable materials demonstrated a significantly higher porosity for incremental fill over bulk fill.

Flexural strength

Figure 4



Caption figure 5: For the letters i, ii, and iii, this demonstrates a statistically significant difference between the sizes for the non-flow groups. As size increases, so does flexural strength. The same goes for non-flow as demonstrated by the numbers 1, 2, and 3. The upper case letters represent a statistically significant difference in strength from those with lower case letters representing the difference in Filtek One vs Filtek Supreme Ultra. The difference in letters (from A to B) represent a statistically significant difference in strength from changing from bulk fill to incremental fill.

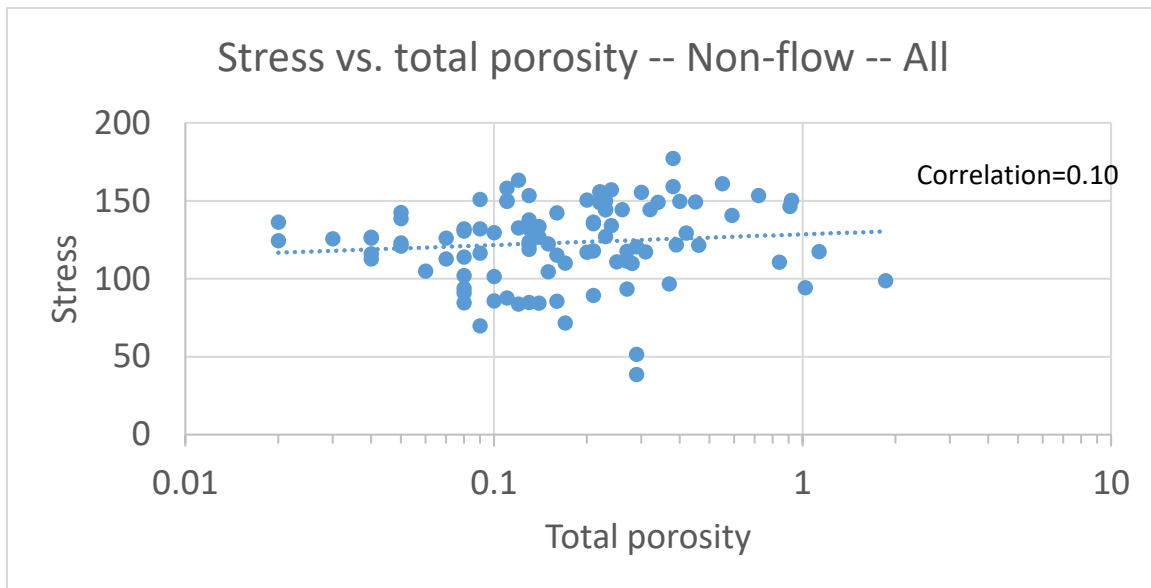
Filtek One – bulk filled yielded the highest strength (137.27 MPa), while Filtek Bulk Fill Flowable – Incremental filled yielded the lowest results (80.08 MPa).

The results of the 3-way ANOVA were separated by flow and not flow due to the flowable having a much lower flexural strength and modulus which highly skewed the results. Flexural strength was statistically higher for the bulk fill vs the incremental fill categories ($p=.005$). Filtek One groups had flexural strengths that were statistically higher ($p<0.001$) than those of the Filtek Supreme Ultra groups regardless of the fill type. For the flowable, the only significant difference was in the size with the bigger sizes having significantly more strength than the smaller sizes.

Flexural modulus was significantly different but in the opposite direction as the flexural strength. Incremental fill groups had lower flexural modulus than the bulk fill groups and the Filtek Supreme Ultra having a higher modulus than Filtek One. For the flowable materials, the incremental fill was found to have a statistically higher modulus than that of the bulk fill groups.

When comparing the strength to that of the porosity, minimal correlation was found (correlation=0.10). Comparative analysis of the 2x2 size showed a significant positive correlation, but there was no association for 2x3 and 2x4 sizes.

Figure 6



Caption Figure 6: There was a no significant correlation between porosity and flexural strength.

Discussion

The objectives of this study were: (1) to nondestructively compare the porosities of a conventional, nanofilled resin-based composite (RBC) with bulk-fill and bulk-fill-flowable RBCs using microtomographic (μ CT) analysis, (2) to investigate whether incremental and bulk-fill techniques can affect the internal porosities of a restoration, and (3) to explore whether the strength of a restoration is related to its internal porosities or voids.

Porosity between composite types

Historically, the only way to find porosity of RBCs was to destructively section the samples and compare them using light microscopy. The destructive nature of the light microscopy test makes it impossible to correlate the results to any type of strength testing. Since the inception of microcomputed tomography in dental research, many factors have been evaluated using this technology to include measurement of enamel thickness, root canal morphology and preparation, micro-finite element modeling, dental tissues engineering, and mineral density (Swain – State of the art of micro-CT applications in dental research). It has also been used to evaluate polymerization shrinkage and marginal integrity or adaptation. Few studies have used μ CT to quantify porosity or voids in dental materials.

Jarisch et al. (2016) theorized that all dental materials contain inherent flaws and that these flaws can create weakness in the material.⁵ Measuring the porosity is a way to measure these flaws that may lead to fracture. Although μ CT is a good way to measure the porosity, it has some limits. In this study the resolution was set at 5 microns which means that any porosity that is smaller than 5 microns was not detected by the machine. Also, in order get the appropriate resolution, only the middle 5mm of each 25mm sample were scanned.

The current study used μ CT to nondestructively evaluate the porosity of Bulk Fill composite RBC, a standard non-flowable microhybrid RBC and a flowable bulk fill RBC. The results revealed that Filtek One had a significantly higher porosity than Filtek Supreme Ultra.

Porosity between bulk fill and incremental fill

Additionally, the study incorporated the variables of placement type: bulk fill or incremental fill. According to the 3-way ANOVA test, the non-flow materials produced no significant difference between the incremental fill and bulk fill groups. However, in the flowable material, incremental fill created a significantly higher porosity ($p < 0.001$) than the bulk fill (.33% vs 0.24%).

Porosity vs strength

Theoretically, the internal porosity of a material would decrease its flexural strength. As the porosity increases, the strength of a material should decrease. However, when looking at the data from the flexural strength, the group that had the second highest porosity (0.32%) had the largest flexural strength (137.27 MPa). When looking at all the data, there was minimal correlation between porosity and flexural strength. Therefore, the null hypothesis is accepted.

Although there is minimal correlation between the porosity and flexural strength, there is a statistically significant difference in flexural strength between the Bulk fill and incremental fill categories. There is a chance that the porosity was not captured by the sensitivity of our equipment, but this begs another question. Why was the flexural strength so much higher for the bulk fill over the incremental fill categories? There must be other factors that contribute to the flexural strength of bulk filled composite restorations.

Conclusion

Within the limitations of this study, RBC restorations that were placed using a bulk fill technique produced a higher flexural strength despite having the higher porosity. Also, the technique used to fill a preparation made no significant difference on the porosity of the sample. More research needs to be done to determine the reason why flexural strength was higher for bulk filled over the incrementally filled resin-based composites.

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