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Micro-computed tomographic evaluation of the effects of pre-heating and sonic delivery on the internal void formation of bulk-fill composites

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The aim of this study was to compare the effects of conventional, sonic or pre-heating insertion techniques on internal void formation of bulk-fill composites with micro-computed tomography. Standardized cylindrical cavities were prepared in 160 human third molars. Four groups received different paste-like bulk-fill composites: SonicFill 2 (SF2); VisCalor Bulk (VCB); Filtek One Bulk-fill restorative (FBF); Tetric EvoCeram Bulk Fill (TEB); and a conventional posterior composite, Clearfil Majesty Posterior (CMP). A hybrid CAD/CAM block was selected as a control (n=10). Composite restorations were built according to each resin composite type and insertion technique (n=10). Micro-CT was used to assess internal void rates. Data was analyzed with two-way ANOVA and Tukey's multiple comparisons test (α=0.05). CAD/CAM blocks were free of voids. For each composite, the highest void rates were observed for the sonic delivery method (p<0.05) except for SF2. SF2 was not affected by insertion techniques (p>0.05). Other composites showed the lowest void rates with pre-heating technique.

Keywords: Composite placement, Internal void, Sonic activation, Pre-heating, Micro-computed tomography

INTRODUCTION

The longevity of dental composite restorations is influenced by the physical and the mechanical properties of the restorative material. These properties mostly depend on the type and amount of monomers in the organic matrix and the type and size of the inorganic filler. Besides these inherent factors, operator related factors could also influence the overall mechanical behavior of the resin composite. During the placement of the resin composite into the cavity, operator could lead to void formation in between the layers of the composites[1]. Moreover, viscosity of the composite material could also affect the void formation incidence[2-4]. Void formations may also result from composite manufacturing process[5]. Such voids and gaps could severely affect the mechanical properties of the composite material[6-8], particularly under fatigue loading, since they could act as stress risers, and may lead to fracture and clinical failures in restorations[9,10]. Furthermore, increase in void amount could lead to increased water sorption and, consequently, cause color change of the composite material[11].

Different techniques such as pre-heating and sonic vibrations have been proposed to bring flowable properties to paste-like resin composites without changing the inherent mechanical characteristics of the composite. Pre-heating of resin composites reduces the film thickness and improves its flow characteristics[12]; thus, the adaptation of composites to the cavity can be improved[13]. Another technique is the use of sonic energy to reduce the viscosity. In this technique, a specially designed handpiece-type device (SonicFill, Kavo Kerr, Orange, CA, USA) creates sonic energy in the tip of the device where a composite enclosed in a unidose compule is attached. This energy lowers the viscosity of the composite during placement. After termination of the sonic energy, the composite reverts to its initial viscous state.

Bulk-fill composites are becoming an acceptable alternative to conventional resin composites. Until the introduction of bulk-fill composites, incremental technique had to be employed for placement of conventional resin composites due to their limited depth of cure. Unlike restoring with paste-like conventional composites, restorations can mostly be completed with a single increment of paste-like bulk-fill composites[14]. These bulk-fill composite materials have gained widespread use thanks to improved curing properties[15], better control of polymerization contraction stresses[16,17] and reduction in cuspal deflection[18,19]. Such improvements allowed the practitioner to use a layer thickness of bulk material up to 4–6 mm instead of 2 mm/layer which is the maximum allowed thickness for conventional composites[20].

Like conventional resin composites, filler types and contents, and matrix compositions of bulk-fill resin composites are quite different from each other[14,21].

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Insertion method may lead to varying amounts of internal voids depending on the material brand since their viscosities may differ with respect to insertion techniques. Despite the few studies that have examined the internal void formation of dental resin composites[1,22-24], there are no studies that have compared the effects of different insertion techniques on internal void formation of different bulk-fill composites.

The purpose of this investigation was to evaluate the effects various insertion techniques (conventional, sonic or pre-heating) on internal void formation in cylindrical Class I cavities filled by a conventional paste-like or different bulk-fill resin composites, assessed with micro-computed tomography (micro-CT). The null hypotheses were that (1) there would be no difference between tested composites regarding the void formation and (2) the insertion techniques would not affect the internal void formation of composites.

MATERIALS AND METHODS

This study was conducted under all the provisions of the World Medical Association Declaration of Helsinki and the local human subjects oversight committee guidelines and policies of the faculty ethics committee for human and animal study (36290600/46).

Tooth selection and cavity preparation

A total of 160 freshly extracted, caries and defect-free human third molars were selected for this study. The occlusal surface was trimmed horizontally with diamond disc attached to a precision cutting machine (Micracut 201, Metkon, Bursa, Turkey) under water-cooling to obtain a flat occlusal surface. Then, standardized cylindrical cavities measuring 5 mm in diameter and 2 mm in depth were prepared in each tooth's occlusal surface using flat disk-shaped diamond burs (5 mm diameter, 2 mm length, 822-806-314-042-524-050, Meisinger, Neuss, Germany) attached to high-speed air-turbine under water cooling. A new bur was used for each cavity preparation.

Assignment of experimental groups

One paste-like conventional posterior resin composite and 4 paste-like bulk-fill resin composites and 1 hybrid CAD/CAM block (Control) were evaluated in this study (Table 1). Ten out of 160 teeth were randomly assigned for CAD/CAM group. Remaining 150 teeth were randomly and equally divided into 5 main groups according to the tested composites. Then each main group was divided into 3 subgroups according to the placement technique; conventional, pre-heating and sonic delivery (n=10) (Fig. 1).

Restorative procedures

After cavity preparations, all specimens were rinsed with distilled water and dried with compressed air prior to adhesive application. A universal adhesive (Single Bond Universal, 3M ESPE, St. Paul, MN, USA) in self-etch mode was used according to the manufacturer's instructions as follows; rubbing the adhesive resin on all surfaces for 20 s, air drying the adhesive for 5 s and light curing for 10 s curing light (SDI Radii Plus, SDI Limited, Bayswater, Australia).

For the conventional composite insertion technique, relevant resin composites were injected directly into the cavity from the deepest part to the top surface using unidose composite compules attached to a composite dispenser (Prisma Compules Gun Dispenser, Dentsply Sirona, York, PA, USA).

For the pre-heating composite insertion technique, a pre-heating device (Caps Warmer, Voco, Cuxhaven, Germany) for unidose composite compules was used for relevant resin composites. Compules were first heated to 68°C for 3 min. Immediately after removal from the pre-heating device, composites were injected into the cavity from the deepest part to the top surface using the same composite dispenser. The mean time elapsed between removing the compules from the heating device and light curing was 28.2±1.4 s.

For the sonic insertion technique, the relevant resin composites were transferred from each of their original compules into the SonicFill compules (Kerr) to be compatible with the SonicFill Handpiece (Kerr) as described by Hirata *et al*.[23]. This process involved, dismantling of the SonicFill compule, emptying of the original content inside the compule, rinsing and immersing in acetone with ultrasonic agitation. After cleaning, composite samples to be evaluated were injected into empty SonicFill compules, and piston was reassembled. Composite compules were attached to the SonicFill handpiece adapted to the dental unit with a high-speed multiflex coupler[25]. Sonic energy was delivered by the handpiece speed at level 3. Air pressure output of the dental unit was measured with pressure gauge to ensure the output pressure was 2.1–3.5 bar as recommended by the manufacturer.

For all insertion techniques a composite filling instrument (Polyfill, 1051/95, Carl Martin, Solingen, Germany) was used vertically to manually adapt the injected composite to the cavity walls. All resin composites were placed in the cavity in single increments, except for CMP, which was placed in two 1 mm-increments as maximum increment indicated by the manufacturer was 1.5 mm. Then, top surfaces were covered with polyester strips under pressure and light cured with the same LED light-curing unit. Tip of the curing unit was in constant contact with the polyester strip during polymerization process. Output power was periodically monitored with the radiometer (Kerr Demetron Model 100 Curing Radiometer Light Meter, Kerr) of the curing unit to ensure intensity of at least 1,000 mW/cm^2. After the polymerization, polyester strips were discarded and the top surfaces of the restorations were wet-finished with a series of graded aluminum oxide disks (Sof-Lex; 3M ESPE); coarse, medium and fine, respectively.

For control group, cavities were scanned using a 3-dimensional (3D) camera (Cerec Omnicam, Dentsply Sirona, Bernsheim, Germany) and digital models were generated by the propriety software (Cerec Software

Table 1 Material type and compositions of restorative materials used in this study

Material	Material type	Recommended insertion technique	Shade	Matrix composition	Filler % by weight	Recommended thickness (mm)	Manufacturer
SonicFill 2 (SF2)	Bulk-fill paste-like	Sonic	A2	Poly(oxy-1,2-ethanediyl), α,α´-[(1-methylethylidene)di-4, 1-phenylene]bis[ω-[(2- methyl-1-oxo-2-propen-1-yl)oxy], 2,2´-ethylenedioxydiethyl dimethacrylate.	81.3	5	Kerr, CA, Orange, USA
VisCalor Bulk (VCB)	Bulk-fill paste-like	Pre-heat	A2	Bis-GMA, aliphatic dimethacrylate, inorganic fillers	83	4	VOCO, Cuxhaven, Germany
Filtek One Bulk-fill Restorative (FBR)	Bulk-fill paste-like	Conventional	A2	AUDMA, AFM, DDMA, UDMA,ytterbium trifluoride, zirconia/slica	76.5	5	3M Dental Products, St.Paul, MN, USA
Tetric EvoCeram Bulk Fill (TEB)	Bulk-fill paste-like	Conventional	IVA (A2)	Bis-GMA, UDMA, Barium glass, YbF3, prepolimer, additives, catalysts, stabilizers, and pigments	76-77	4	Ivoclar Vivadent, Schaan, Liechtenstein
Clearfil Majesty Posterior (CMP)	Conventional paste-like	Conventional	A2	Bis-GMA, TEGDMA, hydrophobic aromatic dimethacrylate, Glass ceramics, surface-treated aluminamicro filler	92	1.5	Kuraray, Okayama, Japan
Lava Ultimate (LA-Control)	Resin nano-cermic CAD/CAM material	Indirect	A2 LT	UDMA, resin nano ceramic containing 79 wt% nanoceramic particles	80	N.A.	3M ESPE, St. Paul, MN, USA

Bis-GMA: bisphenol A-glycidyl methacrylate, AUDMA: aromatic urethane dimethacrylate, AFM: addition- fragmentation monomer, DDMA: dodecyl methacrylate, UDMA: urethane dimethacrylate, TEGDMA: triethyleneglycol dimethacrylate

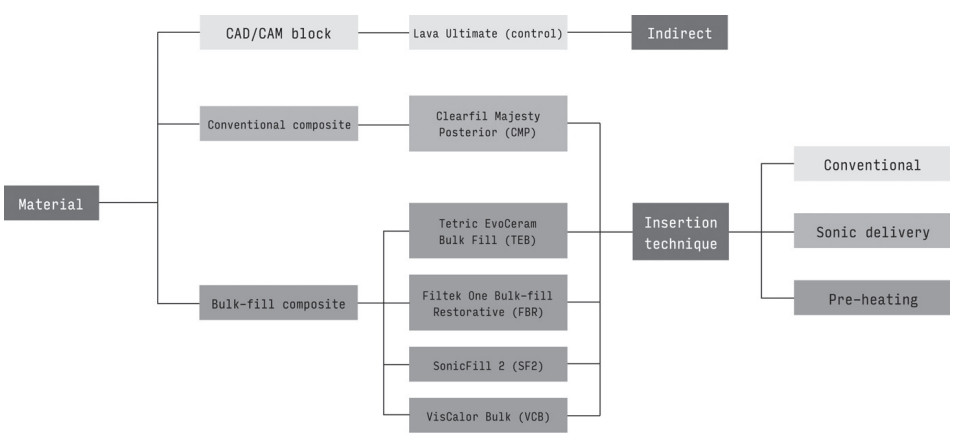


Fig. 1 Experimental setup of the study.

4.6, Dentsply Sirona). After defining the margins of the cavity, CAD-design of the restoration was obtained. A digital preset spacer for the cement gap of 40 μm (InLab MC XL, Dentsply Sirona) was set. Then, restorations were milled out of hybrid composite blocks (Lava Ultimate, 3M ESPE). Manufactured restorations were then bonded with dual-cure resin cement (Panavia V5, Kuraray Noritake Dental, Okayama, Japan) according the manufacturer's instructions.

All restorative procedures were performed by a single operator with 16 years of experience (GD). The specimen preparation and testing were performed at controlled room temperature (25°C).

Micro-CT scanning and image reconstructions

The specimens were scanned with a high-resolution, desktop micro-CT system (Bruker Skyscan 1275, Kontich, Belgium). Scanning parameters were as foloows; 80 kVp, 125-mA, 1.0-mm Al filter, 20 μm pixel size, rotation at 0.6 step and each specimen was scanned 360° within an integration time of 2 min. To minimize ring artifacts air calibration of the detector was performed prior to each scan. The mean time of scanning was around 12 min. The beam hardening correction and optimal contrast limit inputs were set according to manufacturer's instructions.

Reconstructions were performed using reconstruction software (NRecon 1.6.7.2, Skyscan) with a modified algorithm described by Feldkamp *et al.*[26] which was obtained with a 3D density function based on a series of 2-dimensional projections. The axial 2-dimensional images were created using the software, which has the abovementioned algorithm. The other settings included beam-hardening correction, ring artifact correction as already described above were set prior reconstruction of the teeth and the input of optimal contrast limits used as (0–0.1) The lowest limit was set to zero to adjust the density scale had zero origins and the maximum limit was set to the top of the brightness spectrum, representing the highest density value. The contrast limits were applied following the software's instructions. The image data set was 601 axial tomographic slices, each measuring 1,024×1,024 pixels with a 16-bit gray level. CT analyzer software (CTAn, Skyscan, Aartselaar, Belgium) was used for the 3D volumetric analysis and volume of the specimen for micro-CT. The reconstructed images were also further processed for visualization (Skyscan CTVox, Skyscan; The Dataviewer, Skyscan).

Region of interest (ROI) was determined after reconstruction using CT analyzer software through 3D microarchitecture analysis of each specimen. ROI included the entire restoration within the teeth. The restorations were elucidated by making the enamel and dentin translucent. The volume from the 3D structure can be "sculpt out" with the software itself. And the unwanted voxels before visualizing and calculating the voids in and along with the restorations by adjusting brightness and opacity values (Fig. 2).

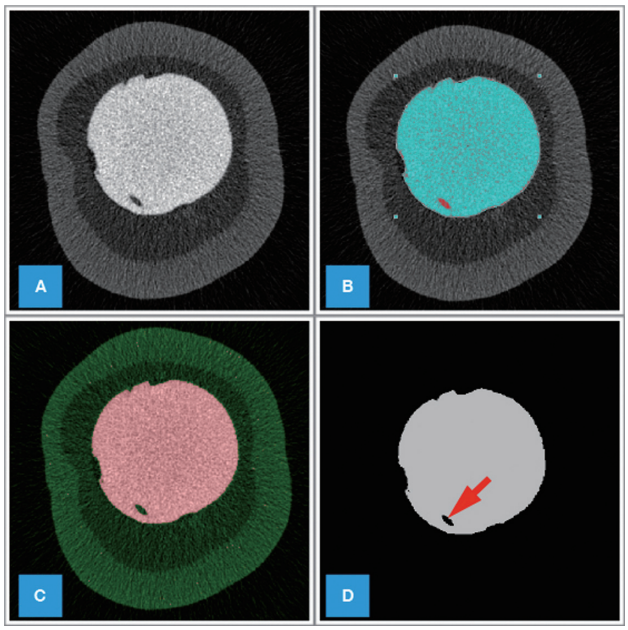


Fig. 2 (A) Resin composite and voids in axially reconstructed micro-CT image. (B) ROI determination for calculation of internal voids in composite mass (blue shows ROI area). (C, D) Automatic subtraction of enamel and dentin from resin and voids and gaps (pink shows segmentation area, red arrow indicate internal voids).

Micro-CT evaluation

The voids in 3D volumes were calculated using the original grayscale images processed with a Gaussian low-pass filter for noise reduction. Enamel and dentin were subtracted from restorations and voids using an automatic segmentation threshold of the CT analyzer software. A global thresholding was used to process the gray level ranges to get an imposed image of only black and white pixels. Then, to calculate the void volumes in the entire restoration a ROI was chosen for each slice. The volume of internal void relative to total restoration volume was calculated (%) by measuring the internal void and restoration volumes each sample.

Statistical analysis

For internal void percentage data, D'Agostino & Pearson omnibus test was used to assess normality. Two-way ANOVA was used to determine the effect of types of resin composites and insertion techniques. Tukey's multiple comparisons test was used for pairwise comparisons. A commercially available software (Prism 6.0, GraphPad Software, La Jolla, CA, USA) was used for all statistical analyses (α=0.05).

RESULTS

The CAD-CAM group (Control) showed no voids (0.00±0.00), and therefore we did not include this group in the statistical analysis not to influence the

Table 2 Multiple comparison results of mean (SD) internal void percentages (%) of the tested composites placed with different techniques (n=10)

	SF2	VCB	FBR	TEB	CMP
Conventional	5.84 (0.11) ^{ABa}	4.57 (0.50) ^{Aa}	5.45 (0.80) ^{ABa}	5.49 (0.83) ^{ABa}	6.00 (0.27) ^{Ba}
Sonic	5.05 (0.47) ^{Aa}	9.73 (0.96) ^{Bb}	11.26 (2.18) ^{Cb}	11.42 (1.33) ^{Cb}	9.65 (0.87) ^{Bb}
Pre-heat	4.77 (0.87) ^{Aa}	2.99 (0.48) ^{Bc}	3.19 (0.43) ^{Bc}	2.57 (0.40) ^{Bc}	5.52 (0.45) ^{Aa}

Means sharing a superscript letter are not significantly different (p>0.05). Uppercase letters compare means in each row. Lowercase letters compare means in each column.
SF2: SonicFill 2, VCB: VisCalor Bulk, FBR: Filtek One Bulk-fill Restorative, TEB: Tetric EvoCeram Bulk Fill, CMP: Clearfil Majesty Posterior

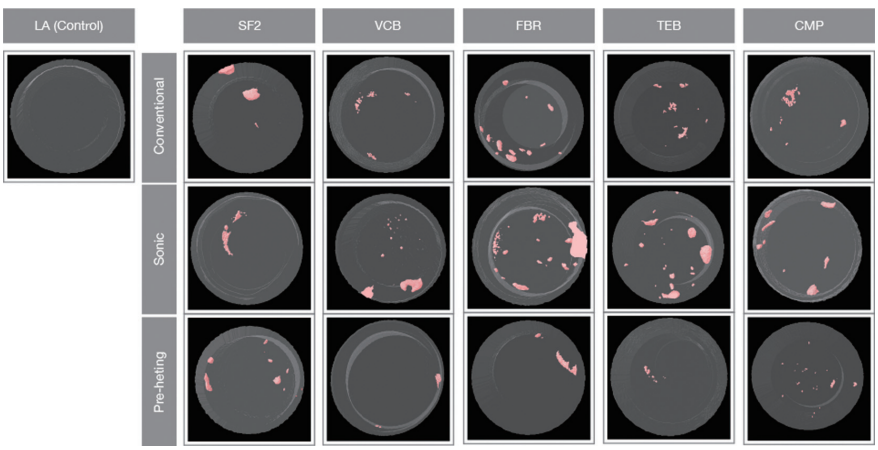


Fig. 3 3D color-coded models of internal void formation for each group (pink shows internal voids; grey area shows restoration).
SF2: SonicFill 2, VCB: VisCalor Bulk, FBR: Filtek One Bulk-fill Restorative, TEB: Tetric EvoCeram Bulk Fill, CMP: Clearfil Majesty Posterior

ANOVA calculations with other groups. For SF2, sonic insertion served as its own control; for VCB, preheating technique served as its own control; for FBR and TEB, conventional insertion served as its own control, which were the insertion techniques recommended by the respective manufacturers. Table 2 presents the mean (±SD) internal void percentage (%) for each material as a function of insertion technique (conventional, sonic and pre-heating) and the Fig. 3 presents 3D models of internal voids for each group.

Micro-CT analysis showed that CAD/CAM blocks were free of voids, which was an expected outcome. All composite groups showed varying degrees of internal voids regardless of the placement method. For each composite, highest void percentages were observed for sonic delivery method compared to conventional and pre-heating methods (p<0.05) except for SF2. SF2 was not affected by insertion techniques (p>0.05). For other bulk-fill composites lowest void rate was observed with pre-heating followed by conventional and sonic insertion techniques, respectively. For the conventional posterior composite (CMP), conventional and preheating insertion techniques showed similar void percentages (p>0.05). Conventional posterior composite and bulk-fill composites showed similar void percentages for the conventional insertion technique (p>0.05).

DISCUSSION

This study evaluated the effect of different insertion techniques on internal void formation of paste-like resin composites by using micro-CT. The results showed that the tested composites showed varying void percentages depending on the material type and placement technique used. Thus, the null hypotheses were rejected.

In this study, a resin nano-ceramic CAD/CAM material was chosen as the control group. This material is made of nano-ceramic particles embedded in a highly cured resin matrix. Since it is a monolithic material, it was chosen as control considering that internal void rate would be minimal or zero compared to resin composites. As expected, no void formation was detected in the control group in this study.

Voids are undesirable porosities, which may negatively influence the mechanical properties of the resin composite[27]. Internal voids within the composite mass may reduce the durability of the composite and may lead to fracture and failures in restorations[9]. Moreover,

they can lead to increased water sorption and contribute to the anisotropic behavior of the composite[8]. Several studies have used micro-CT[1,23,28], optical coherence tomography[24,29] or classical sectioning method[30,31] to evaluate the internal and marginal adaptation or void formation of restorative materials. Specimen sectioning is damaging and labor-intensive process and cannot provide 3D quantification of the entire restoration mass. Contrarily, micro-CT analysis is a non-destructive method for the 3D assessment of materials. Specimens are undamaged and can be used many times. It is proven to be a suitable tool for internal porosity assessment of resin composites[23,32]. In this study, presence and rate of internal voids were evaluated by using micro-CT.

The sonic and pre-heating insertion techniques are alternative methods to conventional placement of resin composites. Theoretically, both approaches would ease the insertion of the material in to the cavity and enhance cavity wall adaptation and reduce internal voids by reducing the material's viscosity, while preserving the composition and physicochemical properties. Ultrasonic energy causes an increase in to yield more random and looser configuration and result in the decrease viscosity of the material in extrusion[33]. Similarly, thermal energy also increases the mobility of the molecular chains of the monomer within the resin and considerably enhances the flowability of conventional paste-like composites[12]. Additionally, pre-heating significantly reduces shrinkage stresses of both paste-like bulk-fill and paste-like conventional dental composites, while preserving or improving the degree of conversion[34].

We observed increased void percentage for sonic delivery method for all tested composites, compared to conventional and pre-heating methods ($p<0.05$) except for SF2. Similar results were observed in another study that reported conventional insertion technique caused less void formation than sonic placement for bulk-fill composites[23]. Researchers speculated that the reduction in resin composite viscosity caused by vibration generated by the sonic hand-piece might result in more air intake into the restoration mass. Moreover, sonication may lead to larger voids by causing gathering of smaller and isolated bubbles already present in the resin. After the resin composite reverts to its original rheological characteristics, air trapped in the material becomes more pronounced and could have a greater impact on the overall properties. Another possible reason for increased void rate in composite mass for the sonic insertion technique might be the use of SonicFill 2 compules instead of the original compules of the tested composites other than SF2. It was suggested that, during manufacturing process, resin composites are filled into the syringes under vacuum which would yield no voids in the material[35]. Since we manually filled the composites into the SonicFill 2 compules, pre-insertion voids might have been introduced. Moreover, they were not specifically formulated for sonic insertion method, thus sonic energy might have negatively influenced the rheological characteristics of these composites, which might have had influence on the outcomes.

In the present study, the lowest void percentage were observed with bulk-fill resin composites (VCB, FBF and TEB) when applied with pre-heating technique. For VCB this is to be expected, since this composite is designed for the pre-heating insertion technique. For FBF and TEB, this outcome was surprising since manufacturers of these composites recommend conventional placement technique. This can be attributed to the reduction of the viscosity of the pre-heated composite resin, however, generalization regarding the viscosity should be done cautiously as each composite material has unique organic matrix and inorganic fillers[36]. In the literature there is not enough information regarding the effect of preheating on the viscosity of bulk fill composites. A study indirectly assessed the effect of preheating on the viscosity of VCB by evaluating the extrusion force and found that the extrusion force for the preheated VCB capsule (68°C for 3 min) was 66.49±14.16 N whereas it was 153.62±1.56 N for the unheated VCB capsule[37]. Another study evaluated the viscosity of FBF at different temperatures, and found that viscosity of FBF at 25°C was 0.05±0.00 kPa s and 0.03±0.01 kPa s at 37°C; which was a 48.7% change in viscosity[38]. Contrarily, preheating did not reduce the void formation of conventional posterior composite (CMP) compared to conventional placement technique. Since this composite was applied in two layers, air trapped between the layers might have caused this outcome.

We used standardized cylindrical Class I cavities to evaluate internal void formation to keep the material volume and configuration factor identical. However, cavity depths were limited to 2 mm to prevent pulpal exposure in the teeth used. As we removed the occlusal enamel, remaining dentin thickness did not allow to prepare cavities deeper than 2 mm in some of the teeth used; therefore, we had to limit the depth of the cavity preparations. Further research will be needed to verify the influence of different cavity configurations and depths, on void formation with various composite insertion techniques. Single sonic energy level (Level 3) and single temperature condition (68°C) was employed in this study. Different sonic energy frequencies, as well as different temperatures may produce different outcomes regarding the internal void rate of resin composites. A limitation of this study was the lack of knowledge about how sonication and pre-heating affect the rheological properties of resin composites. Further studies may focus on this topic.

Based on the results of the present study, the following conclusions may be drawn:

1. Internal void rate in SonicFill restorative material (SF2) was not influenced by different insertion techniques (conventional, sonic or pre-heating).
2. Sonic insertion caused higher void percentages in resin composites other than SF2 with sonic insertion technique compared to other techniques.
3. Although conventional insertion technique was recommended for FBF and TEB by their respective manufacturers, the pre-heating

insertion technique significantly decreased the void percentages.

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