치의과학박사학위논문

Effect of Vibration Device on Internal Adaptation and Void Formation of Bulk-Fill Composite Resin

진동기구가 Bulk-Fill 복합 레진의

내부 적합도와 기포 생성에 미치는 영향

2022 년 8 월

서울대학교 대학원

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Abstract

Effect of Vibration Device on Internal Adaptation and Void Formation of Bulk-Fill Composite Resin

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Objectives. The aim of this study was to investigate the effects of vibration on internal adaptation and void formation of bulk-fill composite resin, according to different frequencies of vibration devices and layering thickness of composite resin.

Methods. The change of complex viscosity when oscillating shear was applied to the Filtek Bulk Fill (FB) composite resin was measured using a rotational rheometer. The frequency and amplitude of two vibration devices (COMO and SONICflex) were measured using a scanning laser doppler vibrometer (SLDV). After preparing cylindrical class I cavities on CAD/CAM hybrid composite blocks, FB was filled using different layering thicknesses (2 mm, 4 mm) and vibration methods (No vibration, COMO, SONICflex) (n = 10). The internal adaptation (2D void area % at the bottom surface) and void formation (3D void volume %) were measured using micro-computed tomography. The median values of the 2D void area (%) and 3D void volume (%) were analyzed using the Kruskal-Wallis test, followed by post-hoc Mann-Whitney U test.

Results. Complex viscosity of FB decreased with increasing frequency of applied oscillation. The frequency and amplitudes of COMO were 149.1 Hz and, 50.5 µm (vertical), 26.4 µm (horizontal) while those of SONICflex were 4,818.9 Hz and 52.1 µm (vertical), 23.3 µm (horizontal). With 2 mm incremental layering, vibration methods demonstrated significantly lower bottom surface void area and lower total void volume than no vibration methods ($p < 0.05$). When vibration was applied with 4 mm bulk filling, there was no significant difference in the bottom surface void area and total void volume ($p > 0.05$). Both vibration devices with different frequencies showed no significant difference in internal adaptation and void volume.

Conclusion. Using vibration devices with 2 mm incremental layering can enhance the internal adaptation and reduce the void volume of bulk-fill composite resin.

Keyword: Bulk-fill composite resin, internal adaptation, micro-CT, vibration, void.

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1. Introduction

Composite resin restoration is currently a widely used dental material because of advancements in the physical property and higher esthetic demands from patients. Physical properties, such as flexure strength, fracture toughness and wear resistance, of composite resin have been improved following the development of filler components and resin monomers.[1] But, the use of composite resin has some shortcomings related to curing depth and polymerization shrinkage.[2] The incremental layering technique has been adopted as the most common composite resin insertion method in order to enhance the polymerization and reduce polymerization shrinkage stress.[3] With a 2 mm thick layer of composite and separate curing, adequate light penetration is achieved to cure the material.[4] Moreover this method decreases the C-factor (the ratio of bonded surface to un-bonded surface), thus reducing the shrinkage stress caused by polymerization shrinkage.[5] However, the incremental technique has some disadvantages, such as increased chair time and void inclusion between the increment layers.[5]

In order to reduce the number of clinical steps of the incremental layering technique and save precious chair time, novel composite resins that can be applied using bulk-fill techniques are available on the market. Manufacturers of bulk-fill composite resin recommend 4 or 5 mm increment fillings in contrast to the maximum 2 mm increments of conventional composite. The use of the bulk fill technique simplifies the restorative procedure and saves clinical time.[6]

Bulk-fill composite resins have improved depth of cure due to the development of specific photo initiators or enhanced translucency. Most composite resins contain camphoroquinone as the primary photo-initiator and a tertiary amine as a co-initiator. Tetric Evoceram Bulk Fill (Ivoclar Vivadent, Schaan, Liechtenstein) contains a dibenzoyl germanium derivative, referred to as Ivocerin, as an additional photo-initiator. Ivocerin is highly reactive to blue range light and helps in polymerization of large increments.[7] Also, changing filler contents and size can enhance the translucency of composites, and as a result, reduce the amount of scatter at the resin-filler interface and increase the depth of cure. The transparency of bulk-fill composite was improved by using large-size particles containing regular-shaped fillers and nano-sized fillers with a diameter smaller than the wavelength of light.[8-10] Accordingly, these technical changes of bulk-fill composite resin improve the curing depth.

To minimize shrinkage stress, the composition of bulk-fill composite resin varies considerably. The amount of polymerization stress is influenced by many characteristics of the composite formulation, such as matrix type, filler content, polymerization kinetics, degree of conversion, and modulus of elasticity.[11] Thus, several attempts have been made to minimize the degree of polymerization stress by changing the formulation of bulk-fill composite resin, which includes reducing reactive sites per unit volume by increasing the filler load with nanometer fillers, increasing the molecular weight per reactive group through the replacement of lower-molecular-weight (TEGDMA) by higher-molecular-weight (UDMA) monomers, or using ring opening polymerizations based on siloranes.[12-14]

However, packing large volumes of bulk-fill composite resin could lead to air bubbles entrapment and create gaps between the restoration and the tooth structure.[5] Increased volume of voids can cause microleakage and discoloration, as well as reduce mechanical strength and bond strength.[15-17]

In this regard, reducing the inflow of voids is important when applying bulk-fill composite resin. Vibration devices for composite resin manipulation have been developed to improve composite resin adaptation in the cavity. It is thought that the vibration reduces the viscosity of composite resin, thus enhancing the flowability of composite resin which increases the cavity adaptation.[18] Vibration devices allow a high viscosity composite resin flows like a low viscosity resin, without the drawbacks of high polymerization shrinkage and poor mechanical properties of low viscosity composite resin.[19] In addition, the repulsing effect of vibration decreases the adhesion between the material and the instrument.[20] Non-stickiness is important in transferring the material to the cavity because the material should not adhere to the instrument but attach to the cavity wall.[21] Thus, vibrations can prevent the formation of voids caused by the pullback of composite resin from the tooth cavity.

Several types of vibration devices for composite resin manipulation are available on the market, but researches to prove their efficacy is limited. In a study by Han et al., who evaluated the effect of a vibration packing device on the adaptation of dental composite resin, the vibration device did not significantly improve the adaptation of composite resin.[22] However, the previous study used only one vibration device and investigated its effect during composite resin restoration of one layer thickness. The findings might not be identical if other vibration devices with different frequencies were applied to varying resin thicknesses. Therefore, the present study investigated the effects of vibration on internal adaptation and void formation of bulk-fill composite resin, according to different frequencies of vibration devices and layering thickness of composite resin. The null hypothesis was that the application of vibration would not affect the internal adaptation and void formation of bulk-fill composite resin, irrespective of layering thicknesses.

2. Materials and Methods

2.1. Materials

This experiment mainly used a nano hybrid composite resin, Filtek Bulk Fill Posterior Restorative (FB, 3M ESPE, St Paul, MN, USA). FB contains two novel methacrylate monomers that lower polymerization stress. A high molecular weight aromatic urethane dimethacrylate (AUDMA) decreases the number of reactive groups, which moderates the volumetric shrinkage. Addition-fragmentation monomers (AFM) contains a third reactive site that cleaves through a fragmentation process during polymerization and provides stress relief. Due to these technical applications, FB showed favorable depth of cure and relatively lower shrinkage stress compared to other bulk-fill resins,[23-25] FB was used as a representative bulk-fill resin in this study.

Artificial cylindrical class I cavities were formed on a CAD/CAM hybrid composite block, Mazic Duro (Vericom, Anyang, Korea). This block has a different degrees of radiopacity compared to composite resin; thus, it is easy to distinguish composite resin, voids, and block on micro computed tomography (micro-CT) image.

The composition of each material is shown in Table 1.

2.2. Rheological measurement

To determine the viscoelastic change of the composite under oscillating shear, a dynamic frequency sweep test was performed. It was conducted with a rotational rheometer (ARES-G2, TA instrument, New Castle, DE, USA) equipped with 8 mm parallel plates set to 2 mm gap distance. The storage modulus G′, loss modulus G″, and complex viscosity η^* were measured at 30℃, at frequencies of 0.1 – 100 Hz. The test was undertaken at a shear strain of 2 %, which is close to the end of linear viscoelastic region and similar to the amplitude of vibration device/specimen thickness (0.05 mm / 2 mm).[22]

2.3. Evaluation of frequency and amplitude of vibration devices

Two packing devices with different vibration frequencies were used to transmit vibration on composite resin. One was COMO (B&L Biotech, Ansan, Korea), which is a motor-driven vibration device designed for dental composite manipulation. A rounded-end tip with 2 mm diameter was used among various changeable tips.

The other device was SONICflex (KAVO, Biberach, Germany), which is a multiuse dental device with a tip change. SONICflex is designed to be placed on the handpiece coupler and vibrates at sonic range frequency by air pressure. This device is available for prophylaxis, endodontics, periodontitis, and minimally invasive preparation, but not for dental composite restoration manipulation. Thus, there was no appropriate SONICflex tip for composite resin packing. To use the same tip for two different vibration devices, a 2 mm round tip originally for COMO was modified to fit on the SONICflex. The COMO tip shank is smooth and cylindrical, while the SONICflex tip shank is screw-shaped. Screw thread with similar pitch and diameter as SONICflex tip was made on a smooth shank of COMO tip using CNC milling machine (Figure 1). SONICflex equipped with a modified COMO tip was used as a vibratory packing device.

The frequency of COMO was 66.8 Hz from the previous study[22] and the frequency of SONICflex is about 6,000 Hz according to the manufacture. In this study, COMO was used as a low frequency vibration device, while SONICflex was used as a high frequency vibration device.

A scanning laser doppler vibrometer (SLDV, Optomet GmbH, Darmstadt, Germany) was used to measure the vibrations of both vibratory devices. The SLDV uses short wave length infrared laser, and the Doppler shift of a reflected laser beam is used to measure vibration velocity.[26]

The vibration device was fixed in place, and the SLDV laser beam was targeted on the vibrating tip to measure the frequency and amplitude of oscillation, both perpendicularly and horizontally (Figure 2). Scans were made over a frequency measurement range of 0 – 5 kHz. Each scan lasted approximately 10 s, with an interval of 20 s between scans. Five repeat vibrometer measurement scans were performed and the frequency and amplitude were measured using SLDV software, OptoGUI (Optomet GmbH).

2.4. Evaluation of composite resin vibration

A cube block with 4 mm × 4 mm × 5 mm (width, height and depth, respectively) cavity was fabricated using a 3D printer (IMC, Carima, Seoul, Korea). One side of the cavity was opened to enable vibration device access. The cavity was filled up with FB, and the block was fixed in place.

A mesh of 12 measure points was placed on the composite resin surface using SLDV as illustrated in Figure 3. Measuring points were arranged at 1 mm, 2 mm, 3 mm, and 4 mm distance from the opened surface. The vibration device tip was placed on the opened surface and provided vibration energy to the filled composite resin. The vibration of the entire grid on composite resin surface was scanned by SLDV, and the vibration was recorded. The SLDV software, OptoSCAN (Optomet GmbH), displayed the vibration as 2D color map and 3D animation; these results visualized how the vibration propagates through the depth of the composite resin.

2.5. Internal adaptation and void measurement using micro-CT

2.5.1. Specimen preparation

Cylindrical Class I cavities, 4 mm diameter and 4 mm depth, were milled on a Mazic Duro block by a CNC milling machine (A-PRO MILL, Namsun, Daejeon, Korea). Two cavities were made on both opposite surfaces of the block for a total of 4 cavities (Figure 4). To verify the accuracy of the cavity, milled cylindrical cavities were digitized using a 3D scanner (T500, Medit, Seoul, Korea) and saved as STL files. The STL data of the cavities were superimposed on each other using metrology software (PointShape Inspector 2.16, DREAMTNS, Seongnam, Korea). The overall deviation was within ± 20 μm, verifying the standardized dimensional accuracy of the milled cavities (Figure 5).

2.5.2. Restorative procedure

Before applying the composite resin, the cavity was sandblasted with 50 μm aluminum oxide (blasting medium, Dentaurum GmbH & Co. KG, Ispringen, Germany) from a distance of 10 mm and a pressure of 2 bar, irrigated with water, and air dried. A silane-coupling agent (Porcelain Primer, Bisco Inc., Schaumburg, IL, USA) was applied and air-dried. A bonding agent (Single Bond Universal, 3M ESPE) was then applied to each cavity and light-cured for 20 s with an LED curing light (Elipar DeepCure-S, 3M ESPE)

Capsule type FB was placed in the cavity using a gun. The tip of capsule touched the cavity floor, and the gun was slowly squeezed while moving it backwards to avoid air entrapment in the composite resin. Composite resin filling was performed with two different layering thicknesses (2 mm incremental layering vs. 4 mm bulk filling) with three different vibration methods (No vibration vs COMO vs SONICflex) for 10 s with 2 strokes/s at 20 ± 2℃. Light curing was performed for 20 s after each application. Table 2 shows the details of every experimental group.

2.5.3. Evaluation of internal adaptation and void volume using micro-CT

Each sample was scanned using a high-resolution micro-CT (Model 1273, SkyScan, Aartselaar, Belgium). Exposure parameters were set at 120 kVp tube voltage, 125 uA tube current, voxel size of 9.88 μm, 0.4 degree rotation step, average 3 frames with an exposure time of 42 min. Aluminum and copper filters were used to suppress beam hardening artifacts. The 2D projection images were transformed into 3D volumes using a reconstruction program (NRecon, ver. 1.7.5.1, SkyScan).

Internal adaptation at the bottom surface was evaluated. In the present study, the internal adaptation was defined as the 2D surface area percentage of the void at the bottom surface. The 2D CT image of the cavity floor was selected and the percentage of the void surface area to the entire floor surface area was calculated by an analyzing software (CT Analyser, ver. 1.18.9.0, SkyScan).

The total void volume (void volume per total cavity volume, %) and void volume of three separated parts (bottom, middle and top) were evaluated using CT Analyser. The bottom part was defined as the bottom floor to 1.3 mm height of the specimen, the middle part as 1.3 mm to 2.6 mm height of the specimen and the top part as 2.6 mm to 3.9 mm height of the specimen. The last 0.1 mm height of the specimen was excluded because large voids were included in the top surface of specimen under the micro CT since it was not perfectly parallel to the bottom surface. The void volume of each part and the total void volume were compared by the vibration devices and incremental technique. The 3D void distribution was visualized using rendering software (CTVox, ver. 3.3.0 r1412, SkyScan).

2.6. Statistical analysis

Levene's test and Shapiro-Wilk test were performed for equality of variances and normality, respectively. As both conditions were not satisfied ($p < 0.05$), non-parametric tests were used for statistical analysis. The median values of the 2D void surface (%) and 3D void volume (%) were analyzed using the Kruskal-Wallis test, followed by post-hoc Mann-Whitney U test with Bonferroni correction for pairwise comparisons. The void volume between incremental techniques was compared using Mann-Whitney U test. All tests were conducted at a level of significance of 0.05. Statistical analyses were performed using IBM SPSS Statistics, v25 (IBM Corp., Armonk. NY, USA).

3. Results

3.1. Rheological measurement

Both the storage modulus G′ and loss modulus G″ increased with increasing frequency (Figure 6). FB showed pseudoplasticiy; the complex viscosity η^* of composite resin decreased with increasing frequency (Figure 7). The η^* decreased from 357,423 Pa·s at frequency 0.1 Hz to 1,936 Pa·s at frequency 100 Hz.

3.2. Evaluation of frequency and amplitude of devices

The mean vibration frequencies and amplitudes measured by SLDV are shown in Table 4. The recorded frequencies of both directions were averaged together and the recorded amplitudes were averaged separately by each direction. The frequency of COMO was 149.1 Hz, while the vertical and horizontal amplitudes of COMO were 50.5 μm and 26.4 μm, respectively (Figure 8). The frequency of SONICflex was 4,818.9 Hz, while the vertical and horizontal amplitudes of SONICflex were 52.1 μm and 23.3 μm, respectively (Figure 9). The frequency of SONICflex was 32 times higher than that of COMO, but the amplitudes of both devices were similar.

3.3. Evaluation of composite resin vibration

Figure 10 shows the representative color map of composite resin vibrations scanned by SLDV. The vibration energy decreases as the depth of the composite resin increases. In general, SONICflex showed more powerful vibration propagation compared to COMO. The vibration energy could propagate 2 – 3 mm into the composite resin, and there was a little vibration left at 4 mm depth for both vibration devices.

3.4. Micro - CT analysis

3.4.1. Internal adaptation

Table 5, Figure 11 present the internal adaptation for each vibration technique and layering thickness. For the 2 mm layering, a significant difference was observed between the no vibration group and the vibration groups (COMO, SONICflex) ($p = 0.005$). Both vibration devices showed similar bottom surface void area, while no vibration showed almost twice the bottom surface void area in comparison with COMO and SONICflex.

For the 4 mm bulk filling, there was no significant difference among all the vibration techniques ($p > 0.05$).

All three vibration techniques showed no significant differences between 2 mm layering and 4 mm bulk filling in bottom surface void area ($p > 0.05$).

Most voids were found at the corner of the cavity through transverse 2D image of micro-CT (Figure 12). When vibration devices were used with 2 mm incremental layering, micro-CT image showed markedly decreased voids at the corner of the cavity.

3.4.2. Voids formation

3.4.2.1. Comparison for 2 mm incremental layering

Table 6, Figure 13 presents the void volume (%) for each vibration technique with 2 mm incremental layering.

For every group with 2 mm incremental filling, the bottom part showed significantly more void volume than the middle and top parts ($p < 0.05$). No significant difference in void volume was observed between the middle and top parts for every 2 mm incremental filling group.

For the bottom part, both vibration groups (COMO, SONICflex) showed significantly lower void volume than the no vibration group ($P = 0.017$). However, for the middle and top parts, only COMO showed consistently lower void volume than the other groups. At the top part, SONICflex showed statistically more void volume than the other two groups ($P = 0.030$).

The void volume of the total cavity was significantly lower in both vibration groups ($P = 0.003$).

3.4.2.2. Comparison for 4 mm bulk filling

Table 7, Figure 13 presents the void volume (%) for each vibration technique with 4 mm bulk filling.

For every group with 4 mm bulk filling, the bottom part showed more void volume than the middle and top parts ($p < 0.05$). No vibration and COMO groups, but not SONICflex group, showed statistically significant difference in void volume between the bottom and middle parts, as well as the bottom and top parts. In SONICflex group, the void volume of the top part was relatively higher than that of the other two groups; only the middle part showed significantly lower void volume than the bottom and top parts.

Comparisons between the vibration techniques showed no significant differences for each part. Also, the total void volume for each vibration group showed no significant difference ($p = 0.432$).

3.4.2.3. 2 mm incremental layering vs 4 mm bulk filling

Comparison between 2 mm layering and 4 mm bulk filling (Table 8) shows that the void volume of the bottom part of 2 mm layering was lower than that of the 4 mm bulk filling for every vibration technique. Regarding the total void volume, 2 mm layering showed lower void volume than 4 mm bulk filling when using vibration devices (COMO, SONICflex) ($p < 0.05$). Without vibration devices, no significant difference in the total void volume was observed between 2 mm layering and 4 mm bulk filling ($p = 0.326$).

Figure 14 shows 3D rendering images of one representative sample for each group. Overall, 2 mm layering showed lower void volume than 4 mm bulk filling, especially when using a vibration device. Internal voids at the bottom surface corner were decreased in 2 mm layering with vibration device use, as shown in 2D micro CT images (Figure 12). Some voids were found at the middle of the cavity in 2 mm layering groups; these were supposed to be entrapped voids between the incremental layers. One special finding is that larger voids were observed at the top part of SONICflex group.

4. Discussion

This study aimed to evaluate the effects of vibration methods and layering thickness on internal adaptation and void formation of bulk-fill composite resin restoration. There was a significant difference in internal adaptation and void formation between no vibration and vibration devices when bulk-fill composite resin was applied with the 2 mm incremental technique. Therefore, the null hypothesis that the application of vibration would not affect the internal adaptation and void formation of bulk-fill composite resin regardless layering thicknesses was rejected.

In the present study, using vibration devices with the 2 mm incremental layering technique demonstrated better internal adaptation and significantly reduced bottom surface void. The correlation between gap formation at the pulpal floor and post-operative sensitivity has long been established,[27] thus, using a vibration device combined with the 2 mm incremental layering technique may help alleviate post-operative sensitivity.

Using vibration devices combined with 2 mm layering also showed significantly less void volume formation. In all cases of this study, the major void volume was concentrated in the bottom of the cavity. When using vibration devices with the 2 mm incremental layering, there was a notable reduction of void volume at the bottom part, thus contributing to the reduction of the total void volume. The presence of an internal void within the composite resin reduces the durability and mechanical property, which may lead to fracture and failure of the resin restoration.[28] From the result of this study, vibration packing devices are thought to reduce internal voids which is beneficial for increasing the durability of resin restoration.

In contrast, in 4 mm bulk filling, the vibration devices showed no effect on both internal adaptation and void formation. Seemingly, the 4 mm bulk layer was too thick for the vibration energy to be effectively delivered to the composite resin for void reduction. Color map from SLDV software also shows that the vibration energy cannot effectively propagate 4 mm depths of composite resin (Figure 10).

Given the high concentration of the voids at the bottom part in all groups, reducing the voids at the bottom of the cavity is important for reducing the total void volume. Flowable resins may provide better adaptation to the cavity walls due to their lower viscosity;[29] thus, applying flowable resin as a liner can enhance the adaptation and reduce the microleakage.[30] High viscosity bulk-fill composite resin with glass ionomer lining can also reduce gap formation and facilitate cavity adaptation.[31] Use of flowable resin or glass ionomer as a liner is also effective in reducing cusp deflection due to low elastic modulus.[32]

Both vibration devices, COMO and SONICflex, showed similar results in this study, even though the vibration frequencies of the two devices differed by more than 32 times (Table 4). For the rheology test, the complex viscosity of FB decreased significantly as the vibration frequency increased. This feature is known as pseudoplasticity and is a common characteristic of composite resin caused by molecular repositioning and separation under shear stress.[33] In Figure 7, as the frequency increased to over 100 Hz, the complex viscosity converged to around 2000 Pa·s, which means that the degree of viscosity reduction by vibration devices might be similar if the vibration frequency is over 100 Hz. The vibration frequencies of COMO and SONICflex were 149.1 Hz and 4818.9 Hz, respectively, and both are greater than 100 Hz. This explains why the two vibration devices showed similar results in the present study. However, at the top part of the cavity, SONICflex showed significantly more void volume than COMO. It is thought that the high vibration energy of SONICflex dispersed the composite resin at the top surface and allowed air intake.

Various studies on the use of vibration devices for composite resin restoration showed conflicting conclusions. Most studies on the effect of vibration on resin restoration are based on the use of the SonicFill system (Kerr, Orange, CA, USA). SonicFill resin incorporates special modifiers that react to sonic energy; the modifier causes the viscosity to drop 87% lower in response to the sonic energy.[34] According to the manufacturer, the increased flowability due to vibration is intended to achieve more precise adaptation to the cavity wall, but the results are controversial. A study that evaluated microleakage in Class II restoration using dye penetration reported that SonicFill had the lowest microleakage values compared with other tested groups.[35] In contrast, studies on gap formation and microleakage reported that SonicFill system showed no significant difference compared with other bulk-fill composites[6,36] and conventional composite resins applied with incremental layering.[34,37] A study evaluating the internal adaptation and gap formation using several bulk-fill composite resins and a conventional resin as a control showed that SonicFill system exhibited significantly larger gaps and less adaptation to the cavity compared with the other tested resins.[38] Also, other studies reported that sonic insertion method increased void formation during resin composite delivery.[18,39] Given that SonicFill is a sonic activated resin delivery system, no more vibration can be applied to condensed composite resin after it is placed on the cavity. Some other vibratory packing devices, such as COMO in this study, are designed to provide vibration energy with packing motion after resin is delivered into the cavity. Therefore, it is difficult to compare the results of the present study to those of studies using SonicFill.

Afifi et al. studied the effect of two oscillating packing instruments, ET3000 (Brassler) and Compothixo (Kerr), which are similar vibration device with COMO, on the marginal adaption of class II restorations.[20] No significant difference on marginal adaptation of resin was observed between the packing techniques when using bulk-fill resin placed in 4 mm layers with a vibratory packing device. This previous result is consistent with our finding that no significant difference was found between the packing devices when resin was placed with 4 mm increment.

Han et al. studied the effect of a vibration device on resin adaption using two composite resins.[22] They used COMO, the same vibration device in the present study, and used Z250 (3M ESPE) and Filtek Bulk Fill. They reported that the vibratory device did not enhance the cavity adaptation of composite resin, which is contrary to the present study findings. However, the authors noted that Filtek Bulk Fill tended to show less gap formation with the vibration, despite the lack of a significant difference. The variability between the present and previous findings could be explained by differences in some experimental features, such as cavity design and composite resin type (syringe type vs capsule type).

One other method to reduce the viscosity of composite resin is preheating of resin before delivery. The preheating of the composite resin exhibited significant decrease of viscosity due to the fact that thermal energy increases the molecular motion of the monomer chain within the composite.[40] Many studies reported better adaptation and lower gap formation with preheated composite resin than composite at room temperature.[39,41,42] Preheating, just like vibration, also improves handling, similar to low viscosity composite resin, without the disadvantage of mechanical limitations.[43] In a previous study comparing preheating and vibration, preheating was more effective than vibration in improving adaptation and decreasing microleakage.[39,44] The viscosity of composite resin decreases as resin temperature increases[45] and is effective in increasing adaptation, but temperature rise is not favorable for pulpal health.[46] High frequency ultrasonic energy can raise composite resin temperature, and both heat and vibration from ultrasonic energy showed significant reduction in void volumes during restoration.[47] In present study, SONICflex produced very high-frequency vibrations, which could affect the temperature of composite resin, but it is difficult to delineate its effect on the volume of voids. Further research may be needed on how vibration at a frequency lower than ultrasonic affects the temperature of composite resin.

SLDV is a non-invasive device for measuring the instantaneous velocity of vibrating objects using the Doppler shift of laser light.[26] The use of a SLDV to measure the vibrating object has replaced accelerometers or other forms of surface-contacting sensors, due to the non-contacting nature of the instrument. SLDV has been used in studies on the measurement of vibration patterns of some dental devices, such as, ultrasonic scalers, high-speed handpieces, endosonic files, and powered tooth brushes.[48-51] In the present study, the frequency and amplitudes of COMO measured by SLDV were 149.1 Hz and 50.5 um (vertical), 26.4 um (horizontal), respectively. These results are quite different from those of Han's study (66.8 Hz, 34 um),[22] mainly because they used a linear variable differential transformer sensor, a contact-type sensor, to measure the frequency and amplitude of the vibrating device. Contact-type sensors should be attached to the vibrating object and can affect the own vibration of the device. The frequency and amplitudes of SONICflex measured in the present study (4818.9 Hz, 52.1 um [vertical], 23.3 um [horizontal]) also differed from the values provided by the manufacturer (6,000 Hz, 120 um). SONICflex is driven by compressed air, and thus air pressure difference due to different circumstances can result in different frequency and amplitude. Further, in this study, we used SONICflex with a modified tip of COMO, not the original SONICflex tip, and this might have affected the frequency and amplitude of SONICflex. Both devices showed similar amplitudes, and the vertical amplitude was higher than the horizontal amplitude.

There are some limitations in present study. Only a nano hybrid composite resin, FB was used, so the effect of vibration on different composite resins of various viscosity should be tested for further study. Standardized cylindrical Class I cavities were prepared for restoration, but different cavity design can affect the vibration propagation and composite resin adaptation. Further studies should be conducted in order to understand the effect of vibration on composite resin adaptation in different cavity designs. In addition, it will be valuable to determine the most suitable vibration frequency that is most suitable for composite resin packing for good adaptation and low void formation.

5. Conclusion

Within the limitations of this study, the main findings are:

(1) Vibration devices were effective in enhancing internal adaptation and reducing void volume for bulk-fill composite resin only when 2 mm incremental layering was adopted.

(2) The void volume of the bottom part was greater compared to that of other parts of the cavity irrespective of resin application method.

(3) The frequencies of COMO and SONICflex were 149.1 Hz, 4818.9 Hz and both two devices had similar effects on internal adaptation and void formation of bulk-fill composite resin.

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Tables and Figures

Table 1. Materials used in this study.

Material (Manufacturer, Lot No.)	**Type**	**Composition**
Filtek Bulk-Fill Posterior Restorative (3M ESPE, 4864A3)	Paste-like bulk-fill composite resin	AUDMA, AFM, DDDMA, UDMA Zirconia/silica, ytterbium trifluoride (76.5 wt%, 58.4 vol%)
Mazic Duro (Vericom, DH0D62A2)	CAD/CAM hybrid composite block	76 wt% nanoceramic particles embedded in highly cross-linked resin matrix, silica, barium glass, zirconia

Composition and filler percentages are from the manufacturers

Abbreviations: AUDMA, aromatic urethane dimethacrylate; AFM, addition-fragmentation monomer; DDDMA, 1, 12 - dodecanediol dimethacrylate; UDMA, urethane dimethacrylate; TEGDMA, triethyleneglycol dimethacrylate.

Table 2. Experimental group description.

Group	Layering thickness	Vibration methods	N
1	2 mm incremental layering	No vibration	10
2	2 mm incremental layering	COMO	10
3	2 mm incremental layering	SONICflex	10
4	4 mm bulk filling	No vibration	10
5	4 mm bulk filling	COMO	10
6	4 mm bulk filling	SONICflex	10

Table 3. Changes in storage modulus, loss modulus, and complex viscosity as a function of frequency.

Frequency (Hz)	Storage modulus G′ (Pa)	Loss modulus G″ (Pa)	Complex viscosity η^* (Pa·s)
0.1	168,920	147,987	357,423
1	131,278	159,829	32,918
10	170,599	365,105	6,414
100	361,987	1,161,610	1,936

Table 4. The mean (SD) frequency and amplitudes of both devices.

Device	Frequency (Hz)	Vertical Amplitude (μm) / Horizontal Amplitude (μm)
COMO	149.1 (0.8)	50.5 (0.6)
		26.4 (1.6)
SONICflex	4,818.9 (17.8)	52.1 (5.0)
		23.3 (2.5)

Table 5. Internal adaptation (void area %) at the bottom surface of the cavity.

	No vibration	COMO	SONICflex	χ^2	*p*
2 mm	15.38 [14.03–21.17] aA	8.72 [5.30–15.47] aB	8.17 [4.51–11.36] aB	10.64	0.005
4 mm	17.15 [11.63–23.05] aA	15.49 [12.43–20.84] aA	13.28 [5.34–23.50] aA	0.42	0.810
U	46	30	28		
p	0.762	0.131	0.096		

$\chi 2$, chi-square; p, p-value.

All of the values are the medians, and the interquartile ranges (first quartile, third quartile) are given in parentheses.

Different lowercase letters indicate statistically significant difference between 2 mm incremental layering and 4 mm bulk-filling for each vibration technique (column).

Different uppercase letters indicate statistically significant difference between vibration techniques (row).

Table 6. Void volume (%) for each group with 2 mm layering.

		No vibration	COMO	SONICflex	χ^2	*p*
2 mm	Bottom	1.85 [1.57–3.49] aA	0.74 [0.23–1.91] aB	1.05 [0.25–1.64] aB	8.18	0.017
	Middle	0.23 [0.04–0.63] bAB	0.01 [0–0.06] bA	0.22 [0.09–0.56] bB	8.95	0.011
	Top	0.08 [0.03–0.35] bAB	0.09 [0.02–0.15] bA	0.26 [0.23–0.34] bB	6.99	0.030
	χ^2	18.21	15.69	6.34		
	p	<0.001	<0.001	0.042		
	Total	1.34 [0.69–1.94] A	0.31 [0.08–0.75] B	0.61 [0.29–0.85] B	11.53	0.003

χ2, chi-square; p, p-value.

All of the values are the medians, and the interquartile ranges (first quartile, third quartile) are given in parentheses.

Different lowercase letters indicate statistically significant difference among bottom, middle, and top parts for each vibration technique (column).

Different uppercase letters indicate statistically significant difference between vibration techniques for each cavity position (row).

Table 7. Void volume (%) for each group with 4 mm bulk filling.

		No vibration	COMO	SONICflex	χ^2	*p*
4 mm	Bottom	3.86 [2.71–5.67]] aA	2.84 [1.25–4.36] aA	3.61 [0.96–6.63] aA	1.04	0.595
	Middle	0.46 [0.08–1.01] bA	0.28 [0.18–0.76] bA	0.51 [0.25–0.67] bA	0.22	0.897
	Top	0.7 [0.21–1.2] bA	0.52 [0.24–1.49] bA	1.62 [0.64–2.14] aA	5.55	0.062
	χ^2	19.86	15.73	12.56		
	p	<0.001	<0.001	0.002		
	Total	1.62 [1.08–2.23] A	1.59 [0.67–2.07] A	2.27 [0.73–3.24] A	1.68	0.432

χ2, chi-square; p, p-value.

All of the values are the medians, and the interquartile ranges (first quartile, third quartile) are given in parentheses.

Different lowercase letters indicate statistically significant difference among bottom, middle, and top parts for each vibration technique (column).

Different uppercase letters indicate statistically significant difference between vibration techniques for each cavity position (row).

Table 8. Void volume (%) for each vibration technique and layering thickness at different locations.

		No vibration	COMO	SONICflex
Bottom	2 mm	1.85 [1.57–3.49] a	0.74 [0.23–1.91] a	1.05 [0.25–1.64] a
	4 mm	3.86 [2.71–5.67] b	2.84 [1.25–4.36] b	3.61 [0.96–6.63] b
	U	80	87	78
	p	0.028	0.005	0.034
Middle	2 mm	0.23 [0.04–0.63] a	0.01 [0–0.06] a	0.22 [0.09–0.56] a
	4 mm	0.46 [0.08–1.01] a	0.28 [0.18–0.76] b	0.51 [0.25–0.67] a
	U	59	78	64
	p	0.496	0.034	0.290
Top	2 mm	0.08 [0.03–0.35] a	0.09 [0.02–0.15] a	0.26 [0.23–0.34] a
	4 mm	0.70 [0.21–1.2] b	0.52 [0.24–1.49] b	1.62 [0.64–2.14] b
	U	85	92	96
	p	0.008	0.001	0.001
Total	2 mm	1.34 [0.69–1.94] a	0.31 [0.08–0.75] a	0.61 [0.29–0.85] a
	4 mm	1.62 [1.08–2.23] a	1.59 [0.67–2.07] b	2.27 [0.73–3.24] b
	U	63	86	87
	p	0.326	0.007	0.005

U, U-value; p, p-value.

All of the values are the medians, and the interquartile ranges (first quartile, third quartile) are given in parentheses.

Different lowercase letters indicate statistically significant difference between 2 mm incremental layering and 4 mm bulk-filling for each vibration technique (column).

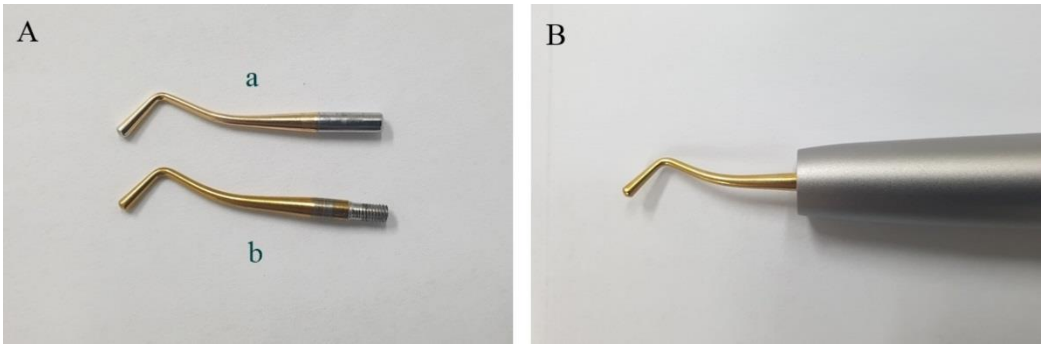


Figure 1. (A) 2 mm round end COMO tip (a) and screw thread was made on a COMO tip shank to fit on SONICflex (b). (B) COMO tip was attached to SONICflex.

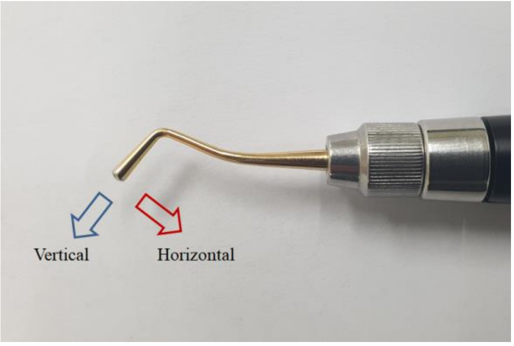


Figure 2. Vibration amplitude of the device was measured vertically and horizontally to the tip.

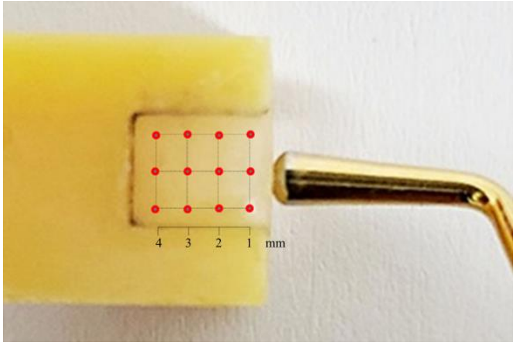


Figure 3. FB was filled in the cavity, and a mesh of 12 points was placed on the composite resin surface using SLDV software. The vibration of each point was scanned by SLDV, and the vibration pattern was visualized by SLDV software.

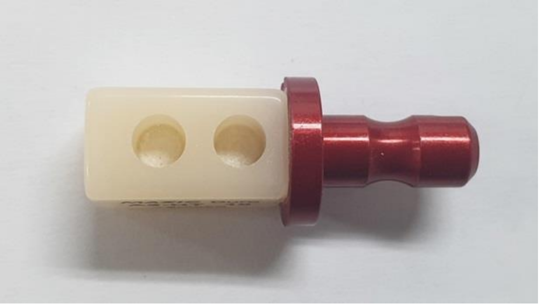


Figure 4. Cylindrical cavities milled on a CAD/CAM hybrid composite resin block (Mazic Duro)

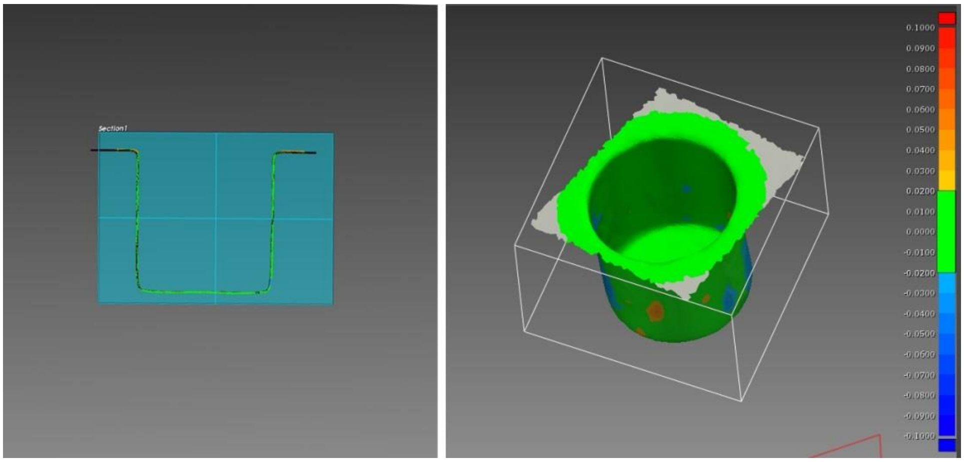


Figure 5. Deviation color map of milled cylindrical cavities. The overall deviation of cavity was around ± 20 μm.

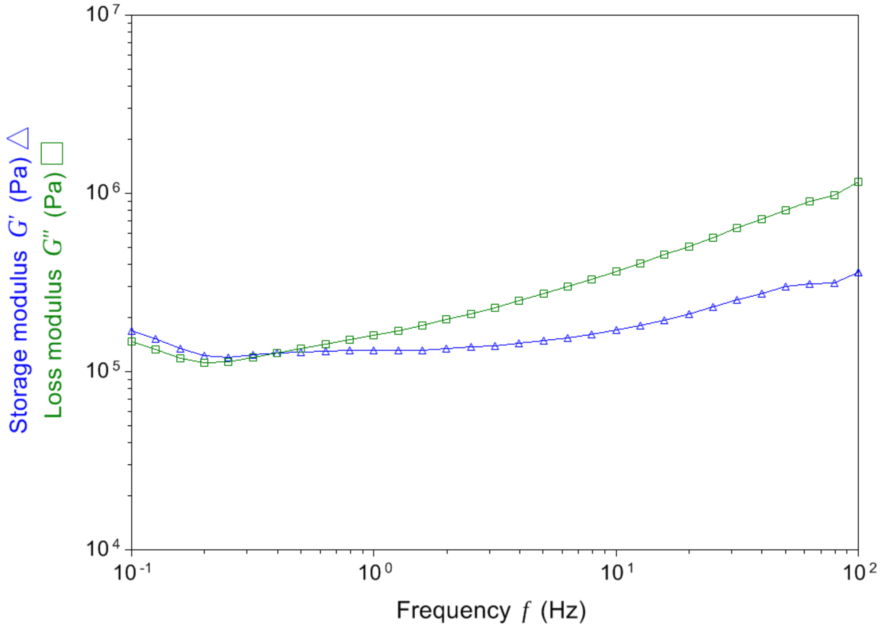


Figure 6. Storage modulus G' and loss modulus G" as a function of frequency.

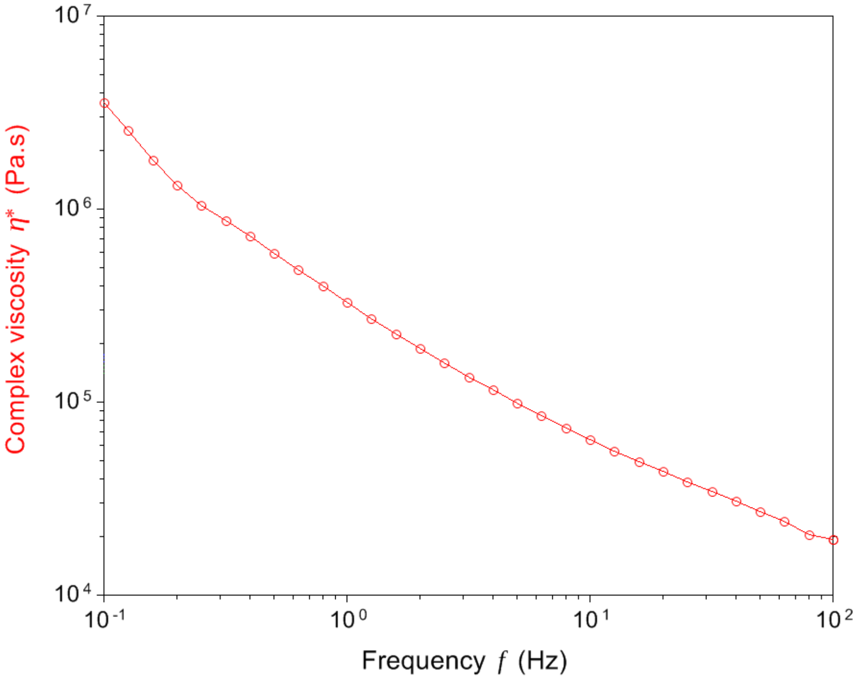


Figure 7. Complex viscosity η^* as a function of frequency.

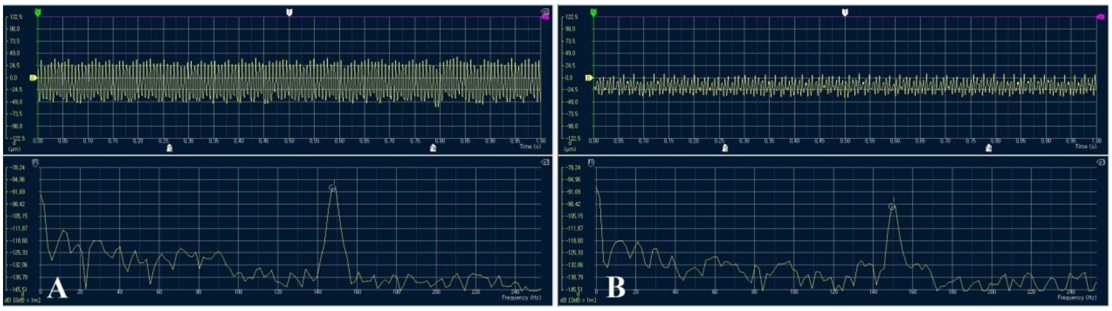


Figure 8. The frequency and amplitude (A : Vertical, B : Horizontal) of COMO on SLDV software (OptoGUI).

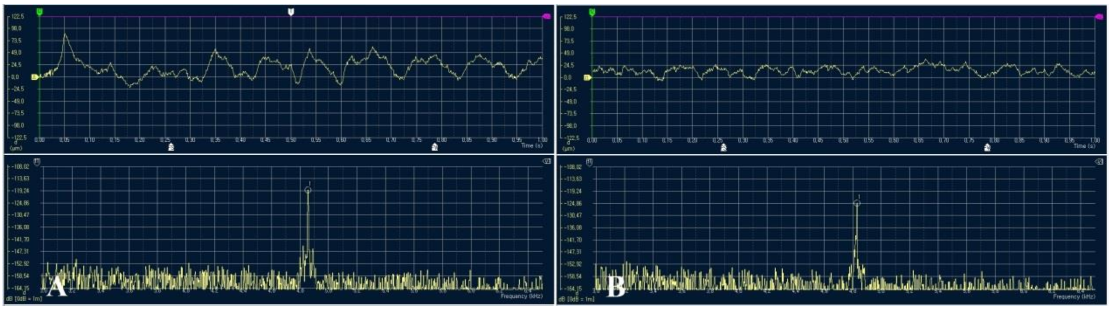


Figure 9. The frequency and amplitude (A : Vertical, B : Horizontal) of SONICflex on SLDV software (OptoGUI).

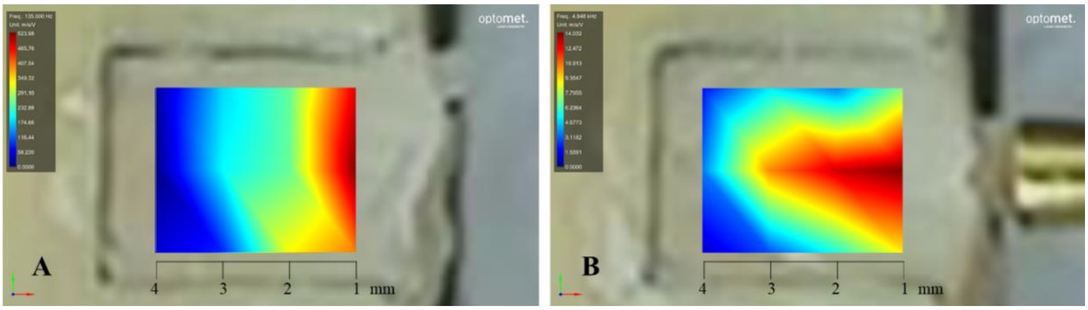


Figure 10. Representative color maps of composite resin vibration by two vibration devices. (A) COMO, (B) SONICflex.

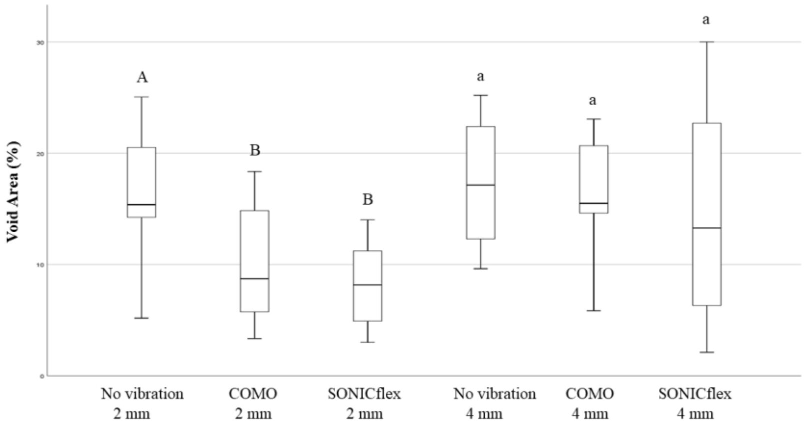
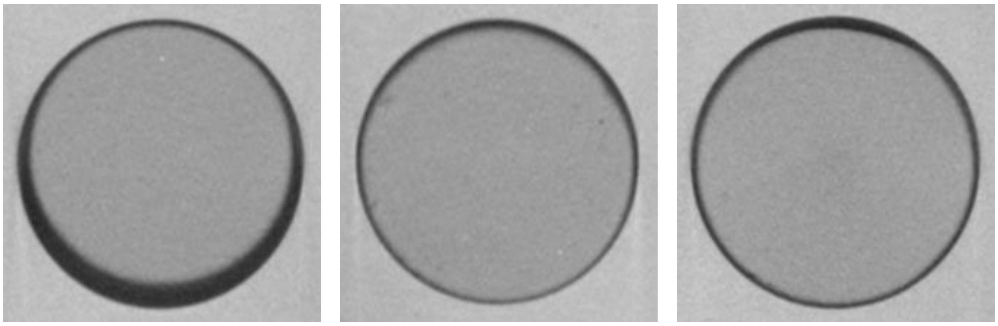
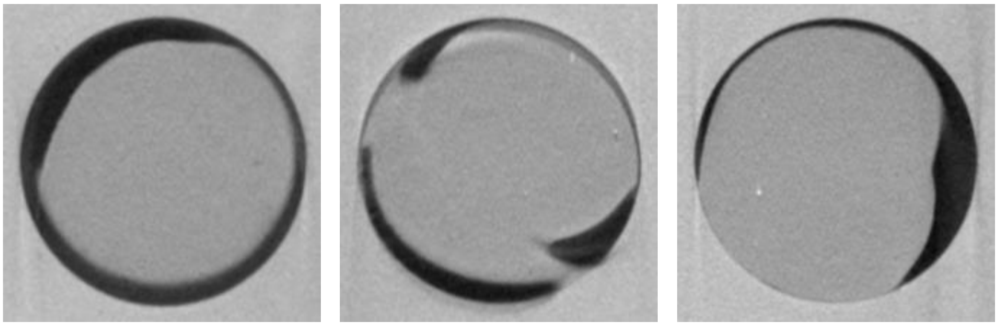


Figure 11. Internal adaptation (surface area %) at the bottom surface of the cavity. Different letters indicate statistically significant difference between each group (2 mm, 4 mm)



No Vibration − 2 mm | COMO - 2 mm | SONICflex - 2 mm



No Vibration - 4 mm | COMO - 4 mm | SONICflex – 4 mm

Figure 12. Representative sample 2D micro-CT image of the bottom surface of the cavity for each group.

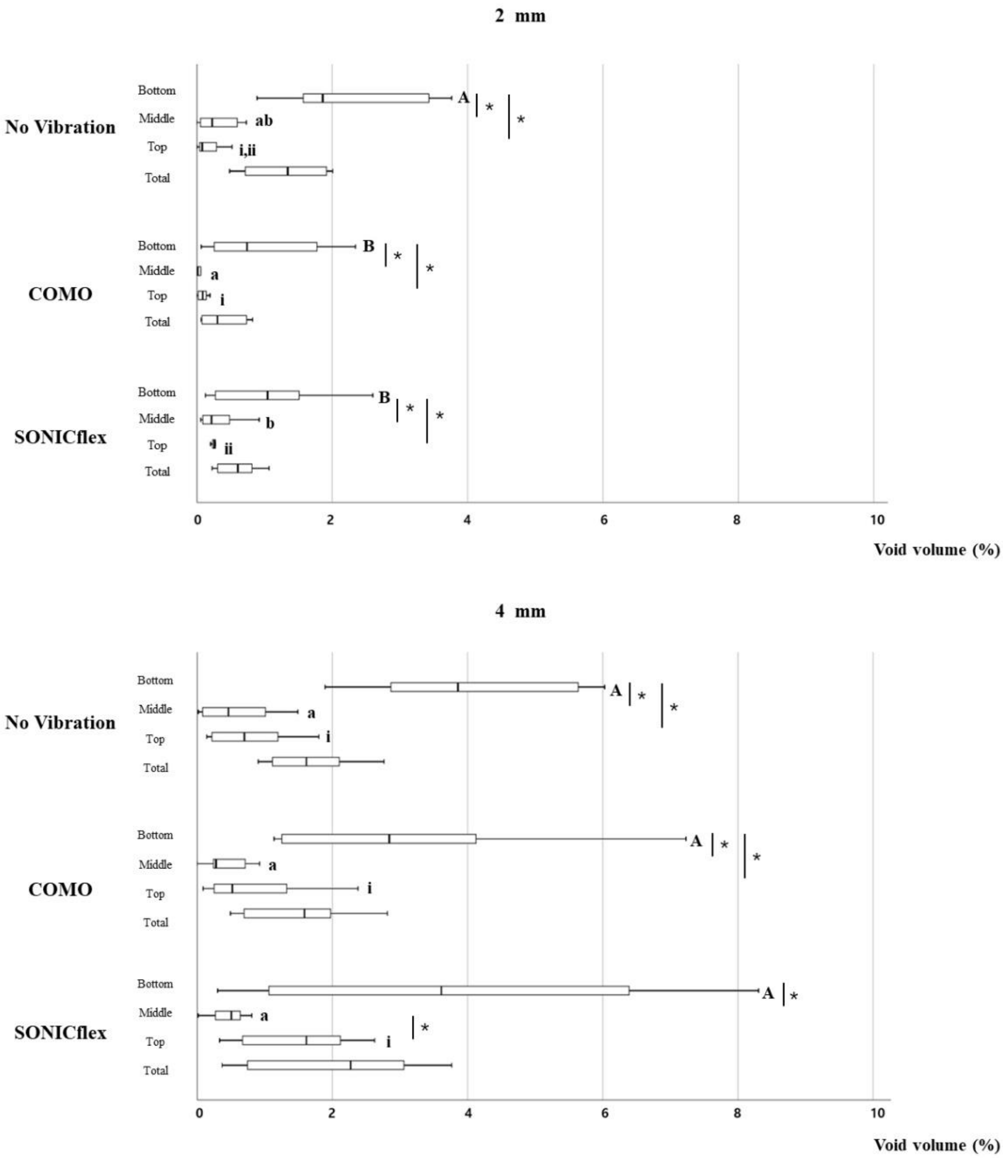


Figure 13. Void volume (%) for each vibration device and layering thickness at different locations.

* indicates statistically significant difference between location of cavity.

Different uppercase letters indicate statistically significant difference between the vibration techniques at bottom part.

Different lowercase letters indicate statistically significant difference between the vibration techniques at middle part.

Different Roman numerals indicate statistically significant difference between the vibration techniques at top part.

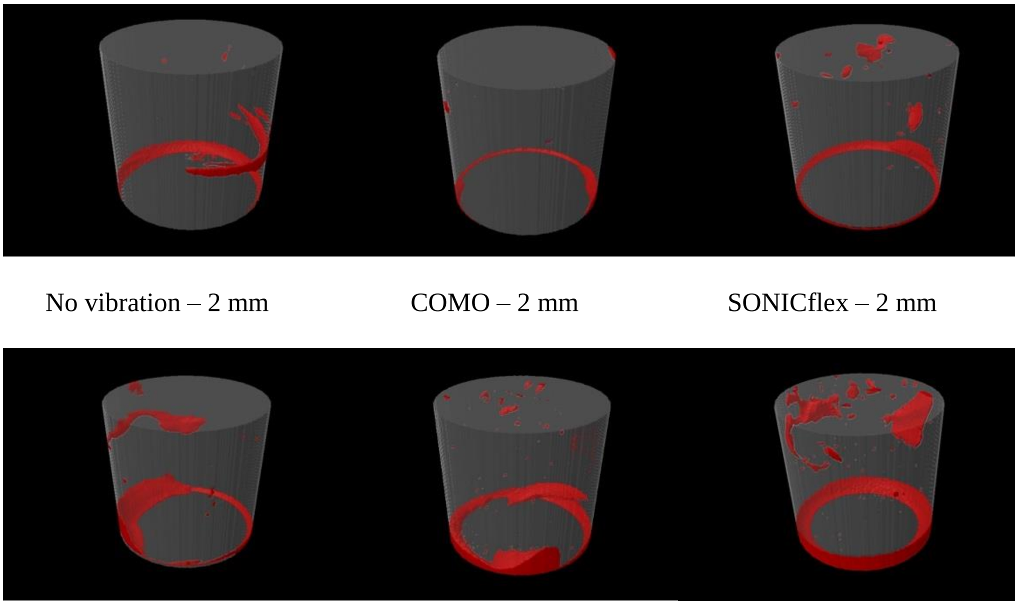


Figure 12. 3D rendering image of one representative sample for each group.

국문 초록

진동기구가 Bulk-Fill 복합 레진의 내부 적합도와 기포 생성에 미치는 영향

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1. 연구 목적

본 연구의 목적은 Bulk-Fill 복합 레진 수복 시 진동기구의 사용과 적층 두께가 복합 레진의 내부 적합도와 기포 생성에 미치는 영향을 알아보고자 하는 것이다.

2. 재료 및 방법

회전형 점성계를 이용하여 Filtek Bulk Fill (FB) 복합 레진에 진동 전

단을 가했을 때의 복소 점도 변화를 측정하였다. 두 가지 진동기구 (COMO, SONICflex)의 진동수와 진폭을 스캐닝 레이져 도플러 진동계 (SLDV)를 이용하여 측정하였다. CAD/CAM 용 하이브리드 컴포짓 블록에 실린더 형태의 1급 와동을 형성한 후 적층 두께 (2 mm, 4 mm) 및 진동 방법 (No vibration, COMO, SONICflex)을 달리하여 복합 레진을 수복하였다 (n=10). 수복된 복합 레진의 내부 적합도 (2D 바닥면의 기포 면적 %) 및 기포 생성 (3D 기포 부피 %)을 마이크로 CT를 이용하여 측정하였다. Kruskal-Wallis 와 Mann-Whitney U test 로 진동 기구 및 적층 방법이 복합레진의 적합도 및 기포 생성에 미치는 영향을 분석하였다.

3. 결과

FB 복합 레진의 복소 점도는 가해지는 진동의 진동수가 커짐에 따라 감소하였다. 측정된 COMO의 진동수 및 진폭은 149.1 Hz, 50.5 μm (수직), 26.4 μm (수평), SONICflex의 진동수 및 진폭은 4818.9 Hz, 52.1 μm (수직), 23.3 μm (수평)이었다. 2 mm 적층 수복 시, 복합 레진에 진동을 가하였을 때 통계적으로 유의하게 바닥면의 기포 면적 감소 및 전체 기포 부피가 감소하였다 ($p < 0.05$). 4 mm bulk-fill 수복 시, 복합 레진에 진동을 가하는 방법은 바닥면의 기포 면적과 전체 기포 부피에 통계적으로 유의한 차이를 보이지 않았다 ($p > 0.05$). 서로 다른 진동수의 두 진동 기구 사이에는 적합도와 기포 생성에 통계적으로 유의한 차

이를 보이지 않았다.

4. 결론

진동기구를 사용하여 2 mm 적층 수복을 하였을 때 bulk-fill 복합 레진의 내부 적합도 증가하였고 기포가 감소하였다.

주요어 : 기포, 마이크로 CT, 벌크필 레진, 적합도, 진동.

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