Title: The effect of composite placement technique on the internal adaptation, gap formation and microshear bond strength

Running title: Micro-ct evaluation of ultrasonically inserted dental resin composites

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ABSTRACT

Purpose: This study aimed to compare the efficiency of placement technique on internal adaptation, gap formation and microshear bond strength (μ SBS) of bulk-fill composite resin materials.

Materials and methods: Standardized class V cavities were prepared for microcomputed tomography (mCT) test and divided into four groups (n=12) as follows: Group SDR: Smart Dentin Replacement system/bulk fill; Group SF2: Sonic-Fill system/bulk fill sonic-activated composite placement system; Group CHU: Herculite-XRV-Ultra composite resin inserted with Compothixo/sonic-vibrated composite resin placement system; Group HIT: Herculite-XRV-Ultra composite resin applied with incremental technique. Self-etch adhesive (Optibond-XTR) was used for bonding in all groups. After 10000 thermocycling, mCT scans were taken to reveal gap formation at the tooth-restoration interface and universal testing machine was used to test microshear bond strength (μ SBS) values (n=10). ANOVA, post-hoc Bonferroni and Tukey HSD tests were used for evaluating the gap formation and μ SBS values (p=0.05).

Results: SF2 and CHU showed the best adaptability compared with both SDR and HIT. The difference between groups SDR and HIT was statistically significant (p<0.05). μ SBS values were found to be the highest for SF2, and the lowest for HIT groups (p>0.05).

Conclusions: Bulk-fill composite resins placed either with sonic-activated or sonic-vibrated instrument demonstrated better adaptability, less gap formation and higher bond strength than both the bulk-fill flowable composite and conventional incremental techniques.

Key words: bulk-fill composite; microcomputed tomography; gap formation; bond strength; sonic instrumentation.

KOMPOZİT YERLEŞTİRME TEKNİĞİNİN ADAPTASYON, BOŞLUK OLUŞUMU VE MİKRO MAKASLAMA BAĞ DAYANIMI ÜZERİNDEKİ ETKİSİ

Öz

Amaç: Bu çalışmanın amacı; bulk-fill rezin kompozitlerin farklı uygulama tekniklerinin, bu materyallerin kavite içine adaptasyon, boşluk oluşumu ve mikro-makaslama bağ dayanımı (mSBS) üzerindeki etkinliklerini karşılaştırmaktır.

Yöntem ve Materyaller: Bilgisayarlı mikro tomografi (mCT) kontrolleri için standardize edilmiş 48 adet Sınıf V kavite hazırlanmış ve dört gruba şu şekilde ayrılmışlardır (n=12): Grup SDR: Smart Dentin Replacement sistemi (bulk fill); Grup SF2: Sonic-Fill sistemi (bulk-fill: sonik enerji ile aktive edilmiş kompozit yerleştirme tekniği); Grup CHU: Herculite-XRV-Ultra rezin kompozitin Compothixo (sonik titreşime sahip el aleti) ile uygulandığı sistem; Grup HIT: Herculite-XRV-Ultra rezin kompozitin geleneksel inkremental teknikle uygulanmasıdır. Kendinden asitli bir adeziv sistem (Optibond-XTR) tüm gruplarda kompozit restorasyonlar öncesi uygulanmıştır. 10000 seferlik termo-siklus işlemi sonrasında tüm örneklerden mCT taramaları alınmış, diş ve dolgu ara yüzünde oluşan boşluklar incelenmiş ve üniversal bir test cihazı ile yapılan mikro makaslama testi ile bağ dayanımları (μ SBS) ölçülmüştür (n=10). İstatistiksel değerlendirmede; boşluk oluşumlarının ve mSBS değerlerinin analizi ve gruplar arası kıyaslanması için tek yönlü varyans ANOVA ve sonrasında post-hoc Bonferroni ve Tukey HSD testleri yapılmıştır (p=0.05).

Bulgular: SF2 ve CHU grupları, tüm gruplar ile kıyaslandığında en iyi kavite içerisine adaptasyon değerlerini vermiştir. SDR ve HIT grupları arasındaki fark ise istatistiksel olarak anlamlı değildir (p<0.05). SF2 grubunda en yüksek μ SBS değerlerine ulaşılırken, en düşük değerler ise HIT grubunda gözlenmiştir (p>0.05).

Sonuçlar: Bulk-fill kompozitler geleneksel inkremental teknikle yerleştirilen rezin kompozitler ile kıyaslandıklarında, hem sonik enerji ile aktive edilen sistemler hem de sonik titreşim yapan el aletleri ile kaviteye yerleştirildiğinde, kavite duvarlarına daha iyi adaptasyon, daha az boşluk oluşumu ve daha yüksek bağlanma dayanımı sergilemektedirler.

Anahtar Kelimeler: Bulk-fill kompozit; Bilgisayarlı mikro-tomografi; Boşluk oluşumu; Bağ dayanımı; Sonik enstrümantasyon.

Introduction

The use of resin-based composite (RBC) materials has been increasing enormously for nearly a decade. Due to the esthetic appearance and mechanically adequate properties, RBCs are the choice of materials. On the other hand, the performance of RBCs is influenced by several factors, including the design and size of the restoration, placement technique and material itself (1). Although most RBCs meet basic expectations of dentists in terms of adhesion, sealing, wear resistance, fracture toughness and biocompatibility, the main deficiencies of RBCs, such as polymerization shrinkage and internal stress, still exist (2,3). Polymerization shrinkage leads to voids, microleakage and debonding of RBCs, generates internal stresses due to contraction, and results in a series of challenges starting with voids, leading to gaps, contamination of composite layers, bond failures between increments and tooth-restoration surfaces (4). Moreover, the presence of voids within the final restoration may cause drawbacks like discoloration due to marginal leakage (5,6). Furthermore, increased wear and microfractures can occur depending on the stress concentration around the voids (7-9). Ultimately, a decrease in bond strength leads to secondary caries and postoperative sensitivity, leading to failure in the final restoration (10).

Various attempts have been made to solve these problems, including increasing the percentage of the filler content in the composite matrix and reducing the size of filler particles (11,12). Several studies have shown that heavier filler loading or decreasing the viscosity of the material would result in an increased bond strength of the material, while others concluded that the percentage of the filler content plays a minor role in adhesion (13-16). However, most studies agreed on the effect of placement techniques, either incremental or bulk-fill, playing a major role in adaptation and polymerization (7,17,18). These techniques are faciolingual layering (vertical), gingiva-occlusal layering (horizontal), the three-site technique, wedge-shaped layering (oblique), the successive cusp build-up technique, the bulk technique, and centripetal build-up (19).

To reduce clinical steps by filling the cavity with a single increment, bulk-fill composite resins and sonic-activated/vibrated placement techniques were recently introduced (12,20). Bulk-fill composite resins can be used as a posterior restorative material, an underlining or a base material under suitable RBCs. These materials can be placed up to 4-mm bulk due to their high viscosity and reactivity to light curing, minimizing the voids, reducing porosity and improving the quality of the final restoration (6,21).

Several techniques have been used to evaluate the gap formation and microleakage at the composite-dentin interface, but most of the results vary due to semiquantitative scoring according to the degree of dye penetration, subjective determination of the visual documents or theoretical characterization of each composite that could not simulate the real shrinkage behavior of in vivo conditions (22,23). Additionally, it is almost impossible to determine and measure the voids within the bulk of the material using conventional methods (17,24). Therefore, a nondestructive and quantitative assessment method, X-ray microcomputed tomography (μ CT), was used in this study to quantify and measure the interfacial gaps and voids and also reconstruct the materials and the surrounding tissues three dimensionally (3D), as well as to distinguish the different components into a range of grayscale values, based on the ability to absorb the X-ray to evaluate properly (25).

The aims of this study were to: 1) compare the placement techniques' efficiency in internal adaptation and gap formation using μ CT; 2) test the microshear bond strength (μ SBS) of bulk-fill composite resin materials; 3) compare the effect of gaps and μ SBS values and reveal whether any positive correlations exist. Although there are former studies focused on these factors, none evaluated the gaps in the RBCs and investigated the correlation between the rate of adaptation and μ SBS of the bulk-fill and conventional RBCs.

The hypotheses of the study were as follows: 1) the shear bond strength will be higher in the sonic-activated/vibrated groups than the incremental placement technique groups, 2) the adaptability and subsequent gap formation will be a statistically different between the bulk-fill and incremental placement technique.

Material and Methods

Ethical statement

Gap formation and shear bond strength were assessed in human molars that were extracted for periodontal reasons; The study protocol has been reviewed and approved by the Ege University Medical Research Ethics Committee (21-5T/66). 96 extracted caries-free human third molars (48 for μ SBS & 48 for μ CT test) were selected to create a pool of teeth for randomization. The teeth were stored in a 2% chloramine solution for a month.

Specimen Preparation for the micro-ct test

Forty-eight double-sided standardized class V cavities were prepared using a cylindrical medium-grit diamond bur (835 314 010; Komet, Lemgo, Germany) mounted in a high-speed

air turbine (650; KaVo, Biberach, Germany) under water cooling. Cavities were prepared in the approximal surfaces to achieve similar enamel and dentin thickness at occlusal and gingival margins of the cavity using these dimensions: width, 3 mm; length, 3 mm; depth, 4 mm. A two-step self-etch adhesive (Optibond-XTR, Kerr Co, CA, USA) was used for bonding in all the groups. The primer was scrubbed with a brushing motion for 20 s on dentine, air thinned for 5 s, subjected to adhesive application for 15 s and was light-cured for 10 s (Demi Ultra; Kerr Corp, Orange Co, CA, USA). The teeth were randomly divided into four groups (n=12): three experimental and one control. The placement techniques were explained below:

Group - I (SDR)

Smart Dentin Replacement (Dentsply, Konstanz, Germany), is a bulk-fill resin composite placed using the bulk-fill method.

Group - II (SF2)

SonicFill2 (Kerr, Sybron Endo, CA, USA), is a bulk-fill resin composite placed using the sonic-activated composite resin placement method. For this group, the SonicFill compule (compatible with the SonicFill Handpiece) was used.

Group - III (CHU)

Herculite Ultra XRV (Kerr, CA, USA) is a conventional resin composite inserted using Compothixo (a portable sonic vibration instrument).

Group - IV (HIT)

Herculite XRV Ultra (Kerr, CA, USA) is inserted using the Incremental Technique (Control group).

The materials used in the study, their composition, mode of application and manufacturer information are shown in Table 1. The specimens were subjected to a thermocycling regimen of 10000 cycles, at $5-55 \pm 8^{\circ}\text{C}$ with a dwell time of 2 min using a thermocycling machine (Delta Tpo2, Nemo, Mashhad, Iran). High-resolution $\mu\text{-CT}$ ($\mu\text{CT 40}$; SCANCO Medical, Switzerland) was used to evaluate the adaptation by measuring the overall gap formation percentage and void dimensions at the cavity floors (occlusal, pulpal, cervical & overall) as well as in the bulk. The imaging settings were as follows: dual-source at 70 kVp; resolution, 8 μm ; nominal isotropic pixel area, 72 μm .

To minimize the changes in the specimen's position during repeated processes, each specimen was mounted on a special template. 2D sagittal images of each specimen were

obtained from the mesial to distal surfaces of the tooth (Figure 1). Nine hundred sagittal cross-sectional images with an interval of 20 μm from the coronal part of the specimens were taken. One hundred slices corresponding to the restoration area (composite-tooth interface) for each specimen at an interval of 30 μm were chosen for the measurements.

To analyze the distribution of gaps at the composite-tooth interface at the occlusal margin (Figure 1a-d), gingival margin (Figure 1e-h) and voids within the bulk of the material surface-rendered 3D volumetric models (Figure 1i-l) of each specimen obtained. The 3D images were analyzed using image analysis software (ImageJ ver. 1.46; National Institutes of Health, Bethesda, MD, USA). The percentage, distribution, cluster form and volumetric quantity of the dark pixels (voids & gaps) as well as the light pixels (tested material and dental hard tissues) were calculated using image analysis software.

Specimen preparation for μsbs test and analysis

Twelve teeth for each group were sectioned parallel to the occlusal surface from the upper middle coronal region ($\sim 1.0\text{-mm}$ thick) and perpendicular to the long axis of the root at one side of the specimen to reach both dentin surfaces, using a water-cooled diamond saw (Isomet, Buehler, IL, USA). The resulting dentin specimens were embedded with the coronal surface exposed in polyvinyl chloride tubes using epoxy resin, both occlusal and polished using wet 400-600-800 grit silicon carbide paper for 60 seconds to create standardized surfaces.

Twenty resin composite cylinders (1.5 mm. diameter & 6.0 mm. length) were constructed on the dentin surfaces (two for each teeth) targeting the center of the dentin while avoiding the pulpal horns and enamel residues. After applying the same adhesive system used in mCT tests, composite cylinders were created with a bonding jig (Ultradent Inc., UT, USA) and cured for 20 s using the same light-emitting diode unit. One of the cylinders on each specimen was constructed parallel to long axis of the tooth to measure the occlusal dentin shear bond strength, while the other cylinder was constructed perpendicular to the long axis of the tooth to measure the axial-pulpal dentin shear bond strength. Two random specimens were excluded prior to the μSBS test due to the technical reasons during composite cylinder construction phase. After thermocycling procedure, cross-sectional radiographs and μCT images were taken from each sample prior to the μSBS test to ensure the adaptation was optimal with no gaps (Figure 2). μSBS was tested using the Universal Testing Machine (Instron Inc., MA, USA) at a crosshead speed of 1.0 mm/min and 50 kg of load cell using a 0.5-mm-wide

chisel. μ SBS values were calculated in MPa by dividing the peak load at failure to the specimen's surface area (10).

Statistical analysis

μ SBS (Mpa), gap formation (%) and maximum void (μm^2) scores obtained from μ CT scans were statistically analyzed using SPSS version 23.0 (IBM Corp, IL, USA). One-way analysis of variance and post hoc Bonferroni test were used for evaluating the gap formation scores and post hoc Tukey HSD test was used for comparing the μ SBS values amongst the groups. Spearman rank correlation test was chosen to determine the correlation relationship between gap formation and μ SBS results ($p=0.05$).

Results

The mean μ SBS for each group is presented in Table 2. The highest mean μ SBS value was observed in the SF2 group (17.62 Mpa). A statistically significant difference in μ SBS was found between the test groups and control group ($p=0.035$). The results of the post hoc Tukey test showed that SDR and CHU demonstrated similar results ($p=0.872$). Therefore, first hypothesis related to shear bond strength is confirmed. Adhesive failures were observed in all samples in the SF2 and SDR groups, while 2 specimens in each CHU and HIT groups exhibited cohesive failures ($p=0.677$) (Figure-2g and 2h).

Total restoration volume for each group were similar ($\sim 35.75 \text{ mm}^3$), void and gap percentages ($\% 10^7$) were be calculated for each group separately according to the bulk volume of the composites. Occlusal, cervical, pulpal and overall mean values (SD) of the maximum void dimensions ($\mu\text{m}^3 \times 10^{-8}$) and overall gap formation percentages observed under μ CT for each group are presented in Table 3 and Figure 3. μ CT images showed that voids within the bulk of the material were observed commonly close to the pulpal walls in all groups (Fig: 1), but the distribution of the voids in the bulk of the material between SDR, SF2, CHU groups was statistically insignificant ($p=0.632$). Additionally, most of the voids occurred close to the pulpal walls ($p=0.044$), and gap formation occurred at pulpal regions ($p=0.039$), with the exception of the SF2 group ($p=0.231$).

The largest void dimensions were observed in “the bulk” of the material for all of the groups, followed by the pulpal and cervical interfaces ($p=0.003$). The pulpal cavity walls exhibited the largest gap formations, but the differences were statistically insignificant compared with the other interfaces ($p=0.462$). The μ CT images showed that SF2 has the best

adaptability, smallest void dimensions ($1.17 \mu\text{m}^3$) and least gap formation ($\% 1,37 \times 10^{-8}$) (Figure 3). Although CHU showed similar void dimensions in the bulk of material ($2,43 \mu\text{m}^3$) as SF2 ($2,08 \mu\text{m}^3$), the differences in the overall void dimensions between CHU vs. SF2 ($p=0.125$) and CHU vs. HIT ($p=0.348$) were statistically insignificant ($p>0.05$). Therefore, second hypothesis related to gap formation is partially accepted.

The correlation significance scores between μSBS and gap formation obtained from Spearman's rho test showed that sonically placed composites SF2 ($r=0.020$), CHU ($r=0.045$) and microhybrid RBC (HIT) ($r=0.010$) presented a negative correlation between gap formation and the μSBS scores ($p=0.001$). On the other hand, no correlation was found between μSBS and gap formation for the SDR group ($r=0.127$).

(Arrows represent voids within the material).

Figure 3. Gap formation percentage (%) observed in occlusal, cervical and pulpal walls.

Table 1. Materials used in the study, composition and manufacturer information.

Material Category	Brand Name	Manufacturer	Filler Concentration	Composition
Nanohybrid Composite	SonicFill2 TM	Kerr Co. USA Kavo, Germany	81 wt%; 63 vol%	2,2'-ethylenedioxydiethyl dimethacrylate, silicon dioxide, titanium dioxide, zinc-oxide, kaolin
Flowable Composite	Surefill SDR	Dentsply. Konstanz. Germany	78 wt%; 45 vol%.	Urethane di-methacrylate resin, di-methacrylate, di-functional diluents, strontium & barium alumino-fluoro-silicate
Microhybrid Composite	Herculite Ultra XRV	Kerr Co. USA	79 wt%; 59 vol%.	Hexamethylene diacrylate, hexane-1,6-diol diacrylate, titanium dioxide, methacrylate ester monomer, zinc oxide,
Self-Etch Adhesive	Optibond XTR	Kerr Co. USA	None	Ethanol, esters with acrylic acid, propylidynetrimethanol, 2-hydroxyethyl methacrylate ethoxylated, trimethylsilyl, propanediylbismethacrylate silanamine, alkalifluorosilicate

Table 2. Mean microshear bond strength values (MPa) (with SD*) of each group. Standard deviation values presented in parenthesis. Significant differences between group were given on table using different superscript letters.

Groups	Minimum μ SBS Value	Maximum μ SBS Values	Occlusal Dentin μ SBS Values	Axio-Pulpal Dentin μ SBS Values	Mean μ SBS Values
Gr-1: SDR	11.902 ^a	23.351 ^a	19.785 (2.42)	13.150 (4.51) ^a	16.468 (3.41) ^a
Gr-2: SF2	9.556 ^b	24.575 ^a	19.982 (3.15)	15.247 (3.99) ^a	17.615 (3.83) ^a
Gr-3: CHU	8.326 ^b	22.821 ^a	17.878 (2.78)	13.084 (4.05) ^a	15.481 (4.50) ^a
Gr-4: HIT	4.855 ^c	16.426 ^b	15.142 (3.02)	6.376 (4.21) ^b	10.759 (3.42) ^b

Table 3. Total restoration volume (mean - mm³), mean void dimensions (μm³) observed in occlusal, cervical, pulpal, in the bulk of the material and the percentage of voids (% 10⁻⁸) acquired from μCT data. Significant differences between group were given on table using different superscript letters.

Groups	TOTAL (Mean)	Occl.	Cerv.	Pulp.	Bulk	Overall
Gr-1: SDR	35.62 mm ³	2.06 ^a	2.21 ^a	2.28 ^a	2.85 ^a	7.41 μm ³ [2.08%] ^a
Gr-2: SF2	35.87 mm ³	1.17 ^b	1.32 ^b	1.34 ^b	2.08 ^a	4.92 μm ³ [1.37%] ^a
Gr-3: CHU	35.39 mm ³	1.45 ^b	1.44 ^b	1.76 ^b	2.43 ^a	5.76 μm ³ [1.62%] ^a
Gr-4: HIT	36.21 mm ³	4.39 ^c	4.47 ^b	4.90 ^c	6.48 ^b	14.85 μm ³ [4.11%] ^b

Discussion

Although many RBC placement techniques are described, success was not achieved in certain cases, especially in class V cavities, which are susceptible to abfraction forces and leakage of gingival sulcus fluid (4,26). Bulk-fill materials, which have self-levelling features, decreased viscosity and polymerization stress, have been developed to enhance the quality of adaptability to the cavity walls (27). However, the filler content and concentration of the bulk-fill materials are associated with some limitations such as microgaps and internal stresses within the material. Therefore, sonic vibrational placement techniques have been developed as an alternative to overcome these challenges (28). In this study, both the microtomographic images and bond strength test results of four materials from each category were investigated to explain the challenges and outcomes of these methods.

Restoration with an RBC involves a rigorous and time-consuming technique that is susceptible to the mechanical properties and chemical composition of the material, as well as the experience of the operator. Both the Bulk-fill SDR and Sonicfill techniques allow condensation of resin composites that can be cured up to a depth of 4-5 mm and at least 20% reduction of the working time compared with the traditional techniques (29,30). Sampaio *et al.*, (31) suggested that SDR is a type of flowable composite, which can be used as a bulk-fill base material and provide better shrinkage and microleakage scores than other flowable RBCs. According to Kapoor *et al.*, (19) SDR is a specially designed RBC and can be used as dentine replacement. Moreover, it showed comparable results to SonicFill when packed in shallow

Class I cavities. Contrary to these results, Benetti *et al.*, (8) showed that in "deep" Class II cavities with a gingival cavosurface margin below the cement-enamel junction, high microleakage values were recorded for SDR when compared with SF2. In our case, SDR showed significantly comparable μ SBS results (16.47 Mpa) to SF2, but lesser adaptability and increased gap formation (13.31%) compared with Sonicfill2. Decreased filler concentration (both weight and volume) and faster application time of the bulk-fill material SDR could be the main reasons for these differences. Even if all precautions have been taken in the placement stage of this study, increased flowability of the SDR may have caused the application to be performed rapidly, resulting in residual air bubbles in the material and close to the internal surfaces.

The restoration technique and precision in application are the most critical factors in determining the mechanical and physical properties of in vitro conditions because all restorative materials contain defects. Voids in RBCs are unavoidable flaws that contribute to make them prone to wear and fracture (32). To minimize the voids within the restorations, every effort was made to place the RBCs as close as possible to the cavity walls by one operator.

In this study, SF2 presented the least gap formation (8.23%) and mean void dimension of $4.92 \mu\text{m}^3$, which corroborate with the study of Furness (33) *et al.*, in which the SF2 system achieved a mean value of 10% in gap formation and SDR and conventional RBC presented similar results. Additionally, the results of a study conducted by Swapna *et al.*, (34) demonstrated that most of the gap formation occurred at the cervical and pulpal cavity walls, followed by the occlusal walls, a finding that was consistent with our findings. This study also proved that the voids within the bulk of RBCs comprised most of the defects. These results can be explained by the working principle of the SF2 system. The composite resin used in this system is a combination of both flowable and universal composite resin that incorporates a highly filled proprietary resin with special modifiers that react to sonic energy. Because sonic energy is applied through the hand piece, the modifier causes the viscosity to drop (up to 87%), increasing the flowability of the composite resin until the sonic energy is stopped and then the viscosity turns into a solid and nonslumping phase (35). In accordance with these results, a study conducted by Rengo *et al.*, (26) showed that low-viscosity restorative materials provide satisfactory bond strengths and reasonable microleakage scores compared with conventional RBCs when "deep" Class V cavities were restored.

Another sonically placed composite resin technique evaluated in this study was Compothixo, which is a vibration condensation instrument. The main difference between the

two sonically activated placement techniques (SF2 vs. CHU) lies in the incrementation and bulk-filling of the RBCs that change the polymerization stress by slowing the radical polymerization rate (36). In this study, CHU showed comparable μ SBS results (15.481 Mpa) with SDR and SF2, while gap formation and void dimensions were relatively better than SDR (11.6%). According to Tolidis *et al.*, (37) conventional RBC packed with the Compothixo System presented better microleakage scores than Sonicfill2 and bulk-fill composites. By contrast, Ortiz *et al.*, (28) compared the adaptation of a fluidized composite resin with a system that modifies its viscosity (Compothixo and SonicFill2) and found a statistically significant difference, showing susceptibility to the formation of the voids at the margins. However, they only measured the cavo-superficial margin using adhesion capability of the selected materials that did not allow evaluation of the degree of total adaptation of a composite resin. Therefore, it is not feasible to evaluate the possible faults that can occur both in the internal margins and within the bulk of the material.

According to our observations, voids commonly occur at internal angles and within material close to the external surfaces of the cavity. In both sonically placed RBCs, an average of 8% (SF2) to 11% (CHU) gap formation was observed; in the bulk-fill placement technique, 13.31% (SDR) gap formation was found. In all groups, the least gap formation was found in the occlusal margins and most of the occlusal gaps were observed at the internal angles. The formation of gaps in the pulpal walls was found to be highest among all groups except for SF2 with a high probability that the unpolymerized RBCs remained in these deeper areas, lost its flowability fast and caused dimensional changes and debonding of the material.

In our study, we evaluated the adaptability of the internal walls as 91% in both sonic-activated placement techniques, a value that is considered satisfactory according to Orlowski *et al.* (27). Regarding the localization of the gaps, it is important to elucidate whether these are the consequences of the placement technique's shortage or polymerization shrinkage generated by viscosity changes or poor adaptation of the RBC. μ CT analysis of our results demonstrated that the sonic-activated-placed high-viscosity bulk-fill resin composite with reduced polymerization contraction (SF2) and sonic-vibrated high-viscosity microhybrid RBC (CHU) resulted in similar void formation and μ SBS to the conventional RBC. In Group CHU and HIT, voids in the transversal μ CT images were consistent with lower μ SBS values.

We acknowledge that polymerization shrinkage is the major factor involved in the development of contraction stresses and gap formation around cavity margins. In this study, a positive correlation was observed between voids and gap formation for all tested materials

consonant to the literature (17,38). The most likely causes are polymerization shrinkage and less likely air bubbles trapped in the material would be the relevant factors affecting the debonding of the material from the cavity walls and decreases the bond strength (33,39). This fact was also confirmed when a negative correlation was observed between gap formation and μ SBS values. Bonding to different dentin regions proved to be an important effect factor on μ SBS values on bond strength and gap formation values indicating that the internal adaptation performance may not be similar inside the cavity walls (40). The negative correlation between bond strength and gap formation may be explained by the influence of tubule orientation and depth of dentin, positively affecting monomeric infiltration when the tubules are wider, as on the depth dentin and perpendicularly configured, as on the pulpal wall (41). In this study, the occlusal surface showed higher bond strength and lower gap formation than the proximal surface in consisted with the literature (39-41).

Conclusions

Sonic-activated insertion technique of bulk-fill composites can serve as an alternative choice in restoration of deep cavities to minimize voids because they have enhanced flowability, leading to good adaptation and increased bond strength.

Ethics Committee Approval: The study protocol has been reviewed and approved by the Ege University Medical Research Ethics Committee (21-5T/66).

Informed Consent: Participants provided informed consent.

Peer-review: Externally peer-reviewed.

Author contributions: CP, DR participated in designing the study. CP, DR participated in generating the data for the study. CP, DR participated in gathering the data for the study. DR, HK participated in the analysis of the data. CP, DR wrote the majority of the original draft of the paper. HK participated in writing the paper. CP has had access to all of the raw data of the study. CP has reviewed the pertinent raw data on which the results and conclusions of this study are based. CP, DR, HK have approved the final version of this paper. CP guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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