Marginal Adaptation of Different Bulk-fill Composites: A Microcomputed Tomography Evaluation

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ABSTRACT

Objectives: In the last decade, bulk-fill materials were introduced to allow resin-based composites (RBC) in one layer (up to 4-5 mm thick) with optimum polymerization. We sought to evaluate the adaptation ability of different bulk-fill composites resin (CRs)and restoration marginal integrity. *Methods*: A total of 28 caries-free and crack-free human molars underwent mesio-occlusal-distal cavity preparation. Each sample prepared the mesial margins on enamel, and the distal margins were extended into dentin. Teeth were then randomly distributed into four groups (n = 7 per group) according to the CR used to restore the cavity. Three bulk-fill CRs—Smart Dentin Replacement Flow+, 3M™ Filtek™ One Bulk Fill (FBF), and Tetric® N-Ceram Bulk Fill (TBF)—and one conventional CR (CC)—Filtek™ Z350—were used. The teeth were then subjected to aging via thermocycling, followed by cyclic loading. Finally, the volumetric width of the interfacial gap at the tooth-restoration interface was measured using a microcomputed tomography (µ-CT) analysis. *Results:* SDR demonstrated the smallest gap volume among all tested CRs, followed by CC in enamel and TBF in dentin after aging. FBF showed the highest gap volume. There was no statistically significant three-way interaction between surface, aging, and material ($p > 0.050$). *Conclusions:* It is safe to suggest using bulk-fill RBC in deep class II cavities instead of conventional layered RBC when dealing with dentin margins. However, further clinical investigation is required.

Since the 1960's when Dr. Bowen introduced composite resin (CR) restorative material, CR has become the most used restorative material in dental clinics.[1,2] One of the significant shortcomings of CR is polymerization shrinkage caused by its methacrylate-based monomer's free-radical polymerization. Further polymerization shrinkage generates internal stresses within the restorations, and the restoration-tooth inter-face that might exceed the bond strength between the resin and the tooth interface can lead to undesirable sequelae.[3–5] Thermal changes and masticatory forces during function may adversely affect adhesive bonding and marginal adaptation.[6,7] Due to differences in thermal expansion and contraction coefficients between CR and tooth structure, internal stresses could develop at the adhesive interface. Combined with masticatory forces, these stresses can lead to debonding, gap formation, and cuspal deformation.[8–12] Marginal gaps allow micro-leakage that can result in discoloration, as post-operative sensitivity, cuspal deformation, and recurrent caries.

Modified CR composition and application techniques have been utilized to overcome some drawbacks, chiefly polymerization shrinkage and gap formation. For example, in the sandwich technique, a glass ionomer base is applied first to reduce the CR volume and reduce shrinkage. Another technique variation, layering, involves the incremental application of CR (each layer being no more than 2 mm thick) to minimize contraction. This process is time-consuming, and the prolonged application time increases sensitivity.[13–15]

In the last decade, CR's material composition has been altered, introducing the bulk-fill CRs, aiming to reduce contraction stress and the number of restorative steps required. Bulk-filling entails CR placement in one layer up to 4–5 mm thick with optimum polymerization. There is no precise classification for a bulk-fill CR, but it is available in two consistencies: low-viscosity (similar to

flowable CRs) and high-viscosity (similar to conventional CRs).[16–18]

Studies have shown that flowable CR can improve marginal adaptation and adhesion by acting as a flexible cushion to absorb stress.[19,20] Manufacturers introduced a low-viscosity bulk-fill CR to promote marginal adaptation, but it had low mechanical properties and required veneering with a conventional CR. This led to creating a high-viscosity bulk-fill CR that manufacturers claim does not need to be layered with conventional CR and can be used as the final restorative material. Despite the rapid release and modification of bulk-fill CRs, there is scientific evidence to support the use of bulk-fill CR as it showed similar performance clinically compared to conventional CR and superior performance in vitro.[21–24,25]

Several in vitro testing methods have been used to measure marginal adaptation and interface gap formation and are direct (clinical, visual, and tactile examination) or indirect (radiographs). These customarily-employed methods have shortcomings. Conventional radiographs are two-dimensional, limiting the ability to study the whole interface, and some direct techniques are destructive. A new and innovative technology, microcomputed tomography (μ-CT), has been introduced to measure marginal integrity and internal adaptation of restorations. It allows for nondestructive evaluation of the tooth-restoration interface in two- and three-dimensions.[26–28]

Some reports suggest that bulk-fill composite reduces cuspal deflection but increases marginal leakage; others assert that bulk-fill CR improves marginal adaptation but increases cuspal deflection.[29–31] This study sought to evaluate the adaptation ability of different bulk-fill composites by evaluating the volumetric changes in the marginal gap size and, by extension, restoration success. Specifically, to identify any differences in marginal gap size after polymerization and aging process concerning the type of resin-based composite (RBC) used. The null hypothesis tested was that there is no difference in gap volume after aging between the tested RBC and tooth structure enamel or dentin.

METHODS

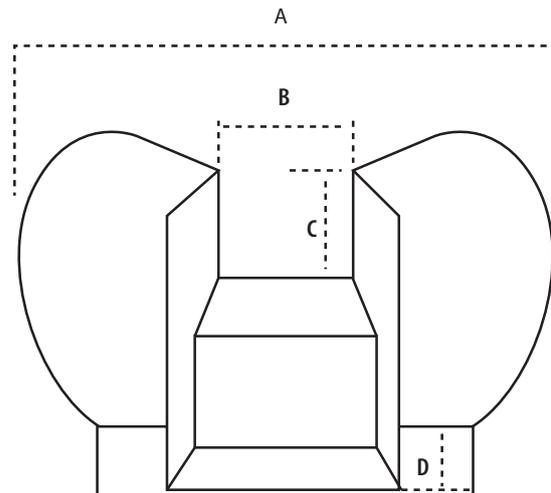Twenty-eight human molars (mandibular molar) free of caries and cracks were extracted for

Figure 1: Cavity preparation configuration. **(a)** Bucco-lingual cusps width (BLW). **(b)** Inter-proximal cavity width (1/3 BLW). **(c)** Enamel margin (above the enamel-cementum junction). **(d)** Dentin margins (1 mm beyond enamel-cementum junction).

periodontal reasons. Written informed consent was obtained from each patient before treatment. Calculus deposits were removed by hand-scaling before random distribution into four groups (n = 7 per group).[32,33] Three bulk-fill CRs—Smart Dentin Replacement SDR Flow+ (SDR) (Dentsply Sirona, York, PA, USA), 3M™ Filtek™ One Bulk Fill (FBF) (3M ESPE, Maplewood, MN, USA), and Tetric® N-Ceram Bulk Fill (TBF) (Ivoclar Vivadent, Schaan, Liechtenstein)—and one conventional composite (CC)—Filtek™ Z350 (3M ESPE, Maplewood, MN, USA)—were used to restore the teeth.

Each molar was prepared using diamond burs with copious water irrigation to receive a standard mesio-occlusal-distal (MOD) cavity in which the width of the isthmus of the preparation was half the bucco-palatal width/buccolingual width (BPW/BLW), and the interproximal box width was one-third the BPW/BLW. Occlusal depth was standardized using 330 burs marked (at 2 mm depth). The cavity was prepared as an extension of the central cavity on the mesial aspect, leaving the enamel margins (4 mm height). A box preparation was extended 1 mm beyond the cementoenamel junction on the distal aspect, leaving the margins on the dentin/cementum[16,34] [Figure 1].

Teeth were etched using a selective etching technique. The enamel was totally-etched using 37% phosphoric acid for 15 seconds, followed
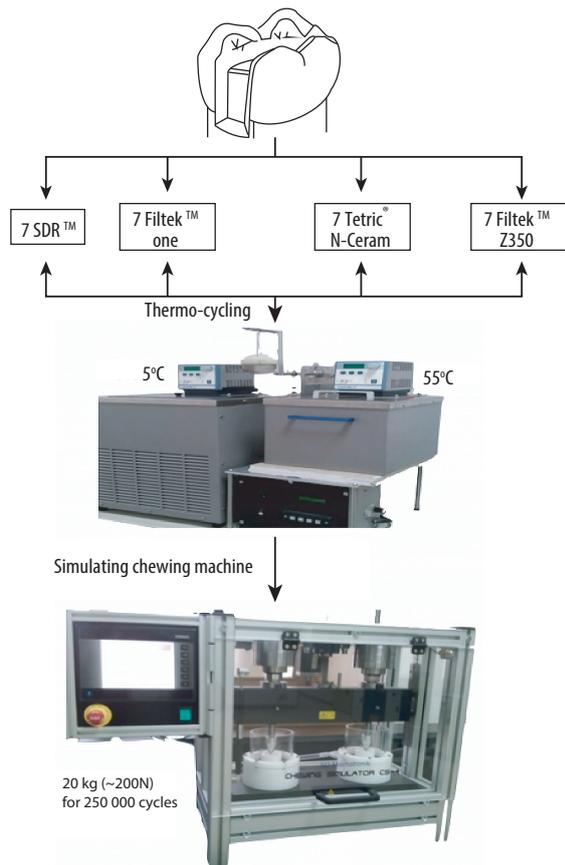
Figure 2: Scheme of the experiment methodology and steps of testing.

by self-etching the dentin using Xeno® IV One Component dental adhesive (Dentsply Sirona, York, PA, USA). The adhesive was applied to both enamel and dentin in a generous layer, scrubbed on dentin for 15 seconds, then air-dried gently for 5 seconds to remove all solvents, and then light-cured for 20 seconds. Each group was restored following the manufacturer's instructions for each corresponding CR; bulk-fill in the bulk of 4 mm each layer and the CC using a layering technique of 2 mm each. Bulk-fill restorations were cured at the occlusal (two overlapping exposures, one mesially-oriented, and one distally-oriented, to ensure full exposure of the occlusal surface), mesial, and distal surfaces for 40 seconds each using a light-emitting diode (LED) light (Bluephase N®, Ivoclar Vivadent, 1140 mW/cm²). While CC was cured for 30 seconds each layer, each composite restoration was finished and polished by 3M™ Sof-Lex™ XT discs (3M ESPE, St. Paul, MN, USA), starting with medium-coarse, then fine, then extra-fine discs.

The aging procedure was conducted through thermocycling and cyclic loading. A total of 5000 thermal cycles (based on the recommendation by the International Organization for Standardization)[35] were performed between 5 °C and 55 °C in deionized water with a 30-second dwell time.[35–37] Cyclic loading was conducted using a chewing simulator (SD Mechatronic, Feldkirchen-Westerham, Germany); the load was produced by weights mounted on vertical bars on a traverse with an individual weight configuration. Utilizing a computer-controlled servo motor,[38] the load used was 20 kg (~200 N) for 250 000 cycles [Figure 2].

Teeth were mounted in clear-acrylic blocks; blocks were marked on one side to ensure exact positioning in the scanner. Teeth were scanned using μ-CT (SkyScan 1176, Bruker-microCT, Kontich, Belgium) to measure the volumetric size of the gap at the tooth-restoration interface. Each tooth was scanned in 360° rotation, and the x-ray tube was operated at 50 kV and 800 μA using a 0.5 mm thick aluminum-copper filter with a resolution of 13.7 μm pixels. Series of cross-sectional images with a voxel size of 11.94 × 11.94 × 11.94 μm were selected using the SkyScan software (CTan version 1.11.10.0 for 2-D visualization). Images were then utilized to assemble 3D visualization of each sample using reconstruction software (NRecon V1.4.0; SkyScan b.v.b.a.). The scan was conducted before restoration, immediately after restoration placement, and after the aging procedure. A qualitative evaluation of the gap was calculated by superimposing each sample's before and after 3D visualization then measuring the gap volume change.

The quantitative data were entered into a computer and analyzed using SPSS (IBM Corp. Released 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.). Descriptive analyses (mean±standard deviation (SD)) were undertaken to present an overview of the findings. The Wilcoxon signed-rank test and two-way analysis of variance (ANOVA) were used in testing statistical significance. The level of statistical significance was set at $\alpha = 0.05$.

RESULTS

The mean gap volume before aging is shown in Figure 3 for enamel and Figure 4 for dentin. The mean gap volume was highest in FBF with enamel margins (0.379), followed by TBF with enamel (0.326), FBF with dentin (0.390), CC with dentin (0.179),
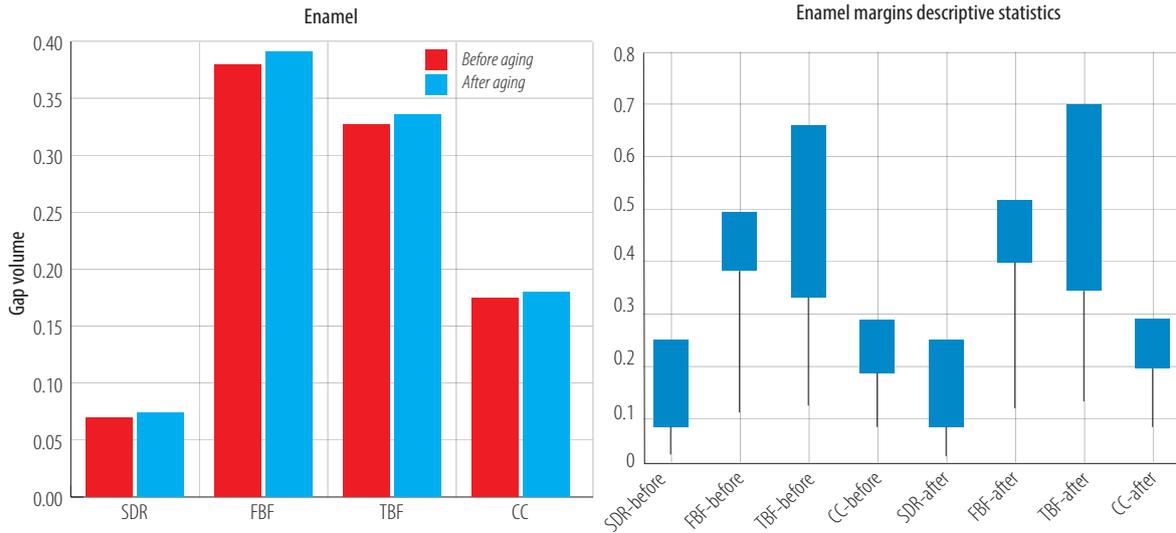
SDR: Smart Dentin Replacement Flow+; FBF: Filtek™ One Bulk Fill; TBF: Tetric® N-Ceram Bulk Fill; CC: conventional composite resin.

Figure 3: The volumetric width of the interfacial gap at the enamel-restoration interface before and after aging and enamel margins-gap descriptive statistics.
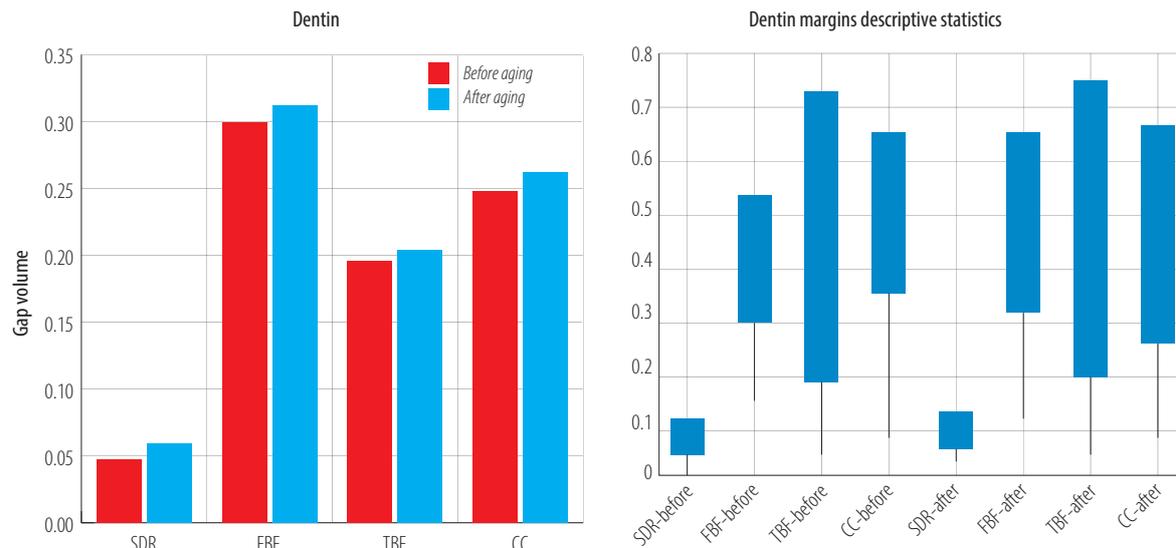
SDR: Smart Dentin Replacement Flow+; FBF: Filtek™ One Bulk Fill; TBF: Tetric® N-Ceram Bulk Fill; CC: conventional composite resin.

Figure 4: The volumetric width of the interfacial gap at the dentin-restoration interface before and after aging and dentin margins-gap descriptive statistics.

Table 1: Statistical results for enamel margin before and after aging.

Material before - after	Mean	Standard deviation
SDR	-0.004	0.003
FBF	-0.010	0.008
TBF	-0.009	0.012
CC	-0.004	0.003

SDR: Smart Dentin Replacement Flow+; FBF: Filtek˜ One Bulk Fill; TBF: Tetric˜ N-Ceram Bulk Fill; CC: conventional composite resin.

Table 2: Statistical results for dentin margin before and after aging.

Material before - after	Mean	Standard deviation
SDR	-0.011	0.012
FBF	-0.012	0.023
TBF	-0.008	0.010
CC	-0.013	0.013

SDR: Smart Dentin Replacement Flow+; FBF: Filtek˜ One Bulk Fill; TBF: Tetric˜ N-Ceram Bulk Fill; CC: conventional composite resin.

Table 3: Two-way interaction between surface, aging, and material.

Source	Type III sum of squares	df	Mean square	F	p-value
Corrected model	1.404[a]	15	0.094	3.369	< 0.001
Intercept	5.541	1	5.541	199.449	< 0.001
S	0.040	1	0.040	1.451	0.231
M	1.191	3	0.397	14.297	< 0.001
S * M	0.169	3	0.056	2.030	0.115

[a]adjusted R squared. S: surface (enamel and dentin); M: material.

TBF with dentin (0.335), CC with enamel (0.175), SDR with enamel (0.069), followed by SDR with dentin (0.074).

The mean gap volume increased for all groups after aging; the Wilcoxon signed-rank test showed statistically significant differences between marginal gap sizes before and after aging for all groups ($p < 0.050$) except FBF with dentin ($p > 0.050$) [Table 1]. The greatest mean difference in gap volume for the tested RBC was seen in FBF with enamel (0.010), followed by CC with dentin (0.013), FBF with dentin (0.012), SDR with dentin (0.011), TBF with enamel (0.009), then TBF with dentin (0.008). The smallest mean difference in gap volume was seen in SDR with enamel (0.004) [Table 1; Figure 3 and Table 2; Figure 4].

Two-way ANOVA revealed a statistically significant difference in the mean gap volume of the four materials before and after aging ($p < 0.001$) but no statistically significant interaction between study factors; surface, aging, and material ($p > 0.050$) [Table 3].

DISCUSSION

The null hypothesis was rejected. The tested RBCs behaved differently upon aging regarding the gap at the tooth-restoration interface.

The use of μ-CT imaging proved useful in measuring restorative adaptation. Unlike other analytical methods that require sample sectioning at multiple time points, μ-CT imaging permits nondestructive evaluation of marginal gaps at different treatment periods; for example, immediately after polymerization and after aging, as in this study [Figure 5].

A marginal gap, or failure to attain intimate adaptation, adversely affects restoration longevity and clinical performance; it can be responsible for post-operative pain and sensitivity, marginal discoloration, recurrent caries, and failure or loss of the restoration.[39,40] Marginal gaps result from an interaction between multiple factors, including the resin composite, cavity design, and restorative procedures. Marginal gap volume is proportional to the polymerization shrinkage value and the resin composite's modulus of elasticity. Polymerization shrinkage generates stress at the tooth-restoration interface due to the modulus of elasticity and strain; greater polymerization shrinkage results in a larger gap.[41,42] A material with a low modulus can compensate for the shrinkage by partially releasing the polymerization stress.[32,43,44]

In this study, factors affecting polymerization shrinkage and gap formation other than the composite were kept constant. Care was taken during cavity preparation to standardize cavity design and dimensions to keep the c-factor the same. A standard adhesive technique with a universal single-bond system was used for all restorations. All samples were light-cured for 40 seconds at all relevant tooth aspects (occlusal, mesial, and distal); increasing the light-curing duration to ≥ 30 seconds, which is longer than manufacturer recommendations, may improve composite polymerization and is recommended by some reports.[16,45]

There was no significant interaction between tooth surface, material, or aging. SDR showed the lowest mean gap volume of all tested materials in both enamel and dentin before aging and in enamel after aging. FBF showed the highest gap in enamel and dentin before aging and the highest gap in enamel after aging. CC showed a high gap volume in dentin before and after aging. The smallest gap in enamel was presented by TBF. TBF, while showing a high gap volume in enamel, had the second-lowest volume in dentin before aging and the second-lowest in dentin after aging. These outcomes agree with those established by previously published studies.[17,46]
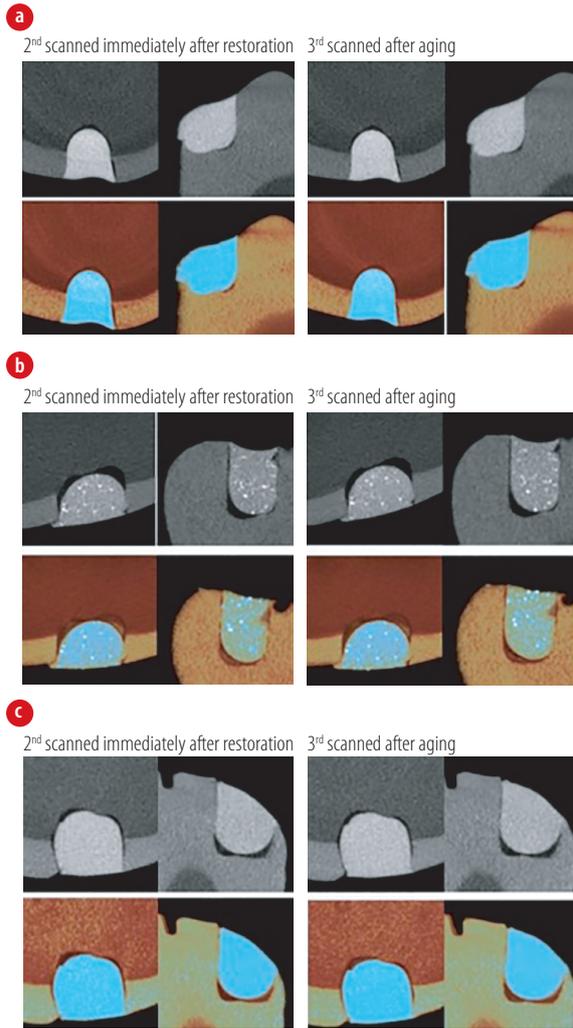
Figure 5: µ-CT imaging of samples immediately after restoration and then after aging, **(a)** Smart Dentin Replacement Flow+, **(b)** Filtek™ One Bulk Fill, and **(c)** conventional composite resin.

According to each manufacturer, the filler particle content by volume is 42.5% for FBF, 45% for SDR, 59.5% for CC, and 55% for TBF. Higher filler content typically reduces the amount of monomer, leading to less shrinkage and polymerization stress. FBF and CC showed shrinkage correlates to the filler content but not the SDR. SDR contains a polymerization modulator in the resin's backbone that reduces polymerization stress. This may explain the smaller gap volumes of SDR restorations detected in this investigation and in previous studies that reported greater marginal integrity using SDR compared to conventionally-layered composites.[47–49]

TBF exhibited better results in dentin than enamel, producing the lowest dentinal gap volume after aging. TBF contains a patented light activator called Ivocerin® with a higher absorption spectrum (range: 350–470 nm), and thus greater photocuring activity than camphorquinone (CQ). This improved the ability to polymerize deep sites during light-curing, may contribute to the positive TBF marginal results in dentin.[50]

It has been reported that when used as a base material, a flowable composite can absorb the impact of mechanical loading due to its lower flexural moduli, resulting in better marginal adaptation upon function.[16,51–53] Similarly, this study determined that SDR and TBF, both flowable bulk-fill RCs, produced the smallest marginal gaps in dentin.

The marginal gaps were more severe in enamel than dentin before and after aging in all groups except for CC. Given that all other factors were kept constant, enamel-dentin discrepancies may be attributed to the modulus of elasticity of each RC used (ranging from 4-5 to 10-11 GPa) closer to dentin than enamel. The comparable moduli of dentin elasticity and resin improve marginal adaptation and adhesive bonding during function (aging), whereas a greater mismatch, seen at the enamel and composite interface, leads to partial debonding and wider gaps.[31,46,47,54] Some published literature agrees with this finding. However, one study showed a contradictory outcome—wider gaps at the dentin margins—that may be due to its inclusion of variable class II cavity designs and involved surfaces (mesio-occlusal, disto-occlusal, and MOD) as well as differences in the duration of thermo-mechanical loading.[49]

A randomized clinical trial is an ultimate method for evaluating the real-life performance of restorations; it is a highly demanding study to conduct, requiring significant funding, participant availability, and compliance. The massive number of new composite materials released into the market complicates matters. In vitro models allow for wide-range screening of materials, highlighting ones with the most practical potential that can be further tested in a controlled clinical trial.

In the current in vitro study, restorations were subjected to thermocycling and cyclic loading to reproduce the stresses that these restorations undergo in the oral cavity during the function. These stresses are generated by polymerization, masticatory load, and mismatched coefficients of thermal expansion and contraction. The findings agree with those published previously; high-viscosity bulk-

fill composites demonstrate better dentin margin integrity than conventionally-layered ones. The marginal adaptation difference was more apparent post-aging.

CONCLUSION

This study revealed that the marginal gap was more significant in enamel than dentin for all tested bulk-fill CR. Compared to CC, bulk-fill composites exhibited better bonding to dentin after aging. Based on in vitro results, the use of bulk-fill instead of conventionally-layered composites in deep class II cavities involving dentin may produce better marginal adaptation upon function. Further clinical study is required to determine the practical, long-term impact of bulk-filled composites, and evaluate the marginal adaptation and clinical performance of high-viscosity bulk-fill composites.

Disclosure
The author declared no conflicts of interest. No funding was received for this study.

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