Evaluation of the effects of shrinkage stress of dental composites with different filling techniques

short thesis for the degree of doctor of philosophy (PhD)

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Publications providing the basis of the thesis:

Néma V; Sáry T; Szántó LF; Braunitzer G; Fráter MT: Rövid üvegszál megerősítésű kompozit által kifejtett polimerizációs stressz. Előzetes tanulmány [Polymerization shrinkage-stress of short fiber-reinforced composite. Pilot study]. FOGORVOSI SZEMLE, 115 (4). pp. 178-182. ISSN 0015-5314 (2022)

Néma V, Sáry T, Szántó FL, Szabó B, Braunitzer G, Lassila L, Garoushi S, Lempel E, Fráter M. Crack propensity of different direct restorative procedures in deep MOD cavities. Clin Oral Investig. 2023 May;27(5):2003-2011. doi: 10.1007/s00784-023-04927-1.
IF: 3.4 (2022) Q1, D1

Néma V, Kunsági-Máté S, Őri Z, Kiss T, Szabó P, Szalma J, Fráter M, Lempel E. Relation between internal adaptation and degree of conversion of short-fiber reinforced resin composites applied in bulk or layered technique in deep MOD cavities. Dent Mater. 2024 Feb 16:S0109-5641(24)00030-7. doi: 10.1016/j.dental.2024.02.013.
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Related publication:

Fráter M, Sáry T, **Néma V**, Braunitzer G, Vallittu P, Lassila L, Garoushi S. Fatigue failure load of immature anterior teeth: influence of different fiber post-core systems. Odontology. 2021 Jan;109(1):222-230. doi: 10.1007/s10266-020-00522-y.

Introduction

Dental resin-based composites (RBCs) are the most frequently used direct restorative materials and have become the first choice for the majority of practitioners worldwide for restoring both anterior and posterior teeth. However, a persistent concern associated with these materials is polymerization shrinkage. This shrinkage prompts stress development not only within the restoration itself and at the interface between the restoration and the tooth, but also within the tooth structure. The ramifications of polymerization stress can give rise to a range of clinically relevant issues, such as the formation of marginal and internal gaps, microleakage leading to infiltration by saliva and bacteria, and even cuspal movement. These factors, in turn, may compromise the long-term success of the restoration.

A recent advancement aimed at mitigating polymerization shrinkage and its associated stress is the introduction of short-fiber reinforced composite (SFRC). It is primarily indicated for dentin replacement in areas bearing high stress due to its distinctive mechanical attributes. Literature suggests that SFRC exhibits reduced polymerization shrinkage when compared to conventional RBC. Furthermore, SFRC demonstrates a decreased propensity for shrinkage-induced crack formation in MOD cavities, whether applied in bulk or increments.

Previous studies have demonstrated the outstanding mechanical properties of SFRC materials.

However, there are no studies comparing the use of SFRC materials in bulk-fill versus layering techniques to determine if there is any clinically relevant benefit of one over the other. This raises the question of whether the different application methods result in differences in polymerization shrinkage and its subsequent effects. The objective of our investigations was to assess crack formation (study I) associated with different direct restorative procedures in deep class II MOD cavities. Additionally, we aimed to evaluate the internal adaptation, porosity, and degree of conversion (study II) within the aforementioned restorative techniques in these deep MOD cavities.

Methods

A total of 200 mandibular third molars extracted for orthodontic reasons were used. The selected caries-free mandibular third molars had the following dimensions: 8–10 mm oro-vestibular diameter, 9–11 mm mesio-distal diameter, and 6–7 mm crown height measured from the cemento-enamel junction. During the entire study period, between the measurements, the teeth were stored in 0.9% saline solution at room temperature.

Class II MOD cavities were prepared in all 200 teeth. The cavities were 5 mm deep and their oral and vestibular walls were 2.5 mm wide each. After cavity preparation, the teeth were screened for enamel cracks with D-Light Pro (GC

Europe, Leuven, Belgium) in "detection mode," at ×4.3 magnification

All prepared teeth underwent the same adhesive treatment. The class II cavities were first modified to class I using the centripetal technique, building up the proximal walls with conventional RBC (G-aenial Posterior A3, GC Europe). Then, the cavities were restored in either of the following ways in both the Study I. and II.: The study groups, application methods, the investigated materials, and their composition are presented in Table 1.

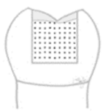
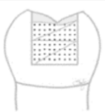
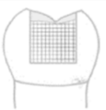
Group		Application method	Material	Manufacturer	Shade	Organic matrix	Filler	Filler loading (vol%/wt%)
Group 1*		HV SFRC 4mm bulk layer	EverX Posterior	GC Europe, Leuven, Belgium	U	BisGMA, TEGDMA, PMMA	0.7µm barium glass (65.2%), 17µmx1-2mm short E-glass fibers (9%)	53.6/74.2
Group 2*		HV SFRC in 2x2mm incremental layers						
Group 3*		LV bulk-fill RBC in 4mm	Surefil SDR Flow+	Dentsply, Milford, DE, USA	U	Modified UDMA, TEGDMA, DMA, TMA	4.2µm Ba-Al-F-B silicate glass, Sr-Al-F silica, YbF	47.4/70.5
Group 4 (Control)		HV conventional RBC in 2x2mm incremental layers	G-aenial Posterior	GC Europe, Leuven, Belgium	A3	UDMA, TCDDD, DMA	F-Al-silicate, Sr-glass, lanthanide-F	65.0/77.0

Table 1 Study groups, materials, application methods, manufacturers, and composition of the investigated resin

*based composites. * 1mm covering with G-aenial posterior RBC*

Study I. Assessment of cracks in the restored teeth

Screening for cracks was performed with D-Light Pro (GC Europe) at ×4.3 magnification under transillumination with the “detection mode,” utilizing a protocol requiring two- examiner agreement (Fig. 1A) The teeth were screened for cracks two times: first after the last polymerization phase and then 1 week later. Between the two sessions, the teeth were kept in physiological saline solution.

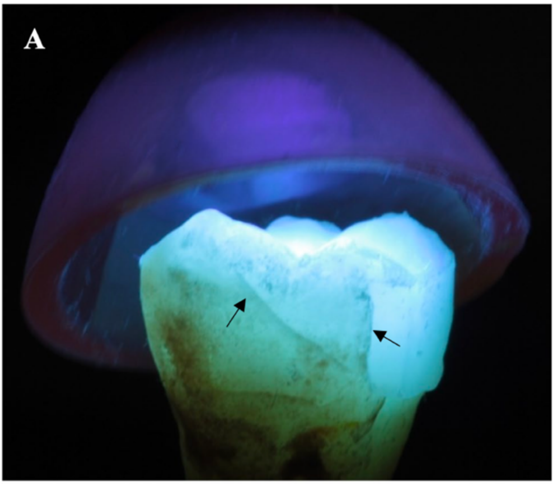


Figure 1A Examples of cracks (arrows) developing during the polymerization process

Study II Assessment of internal adaptation and the degree of conversion

Micro-computed tomography measurements – 3D internal adaptation and porosity

To analyze the 3D internal adaptation and closed pore volume micro-computed tomography (micro-CT) scans were performed (Skyscan 1176 Control Program: version 1.1 (build 12), Bruker, Kontich, Belgium) of the 80 samples after one month from the polymerization.

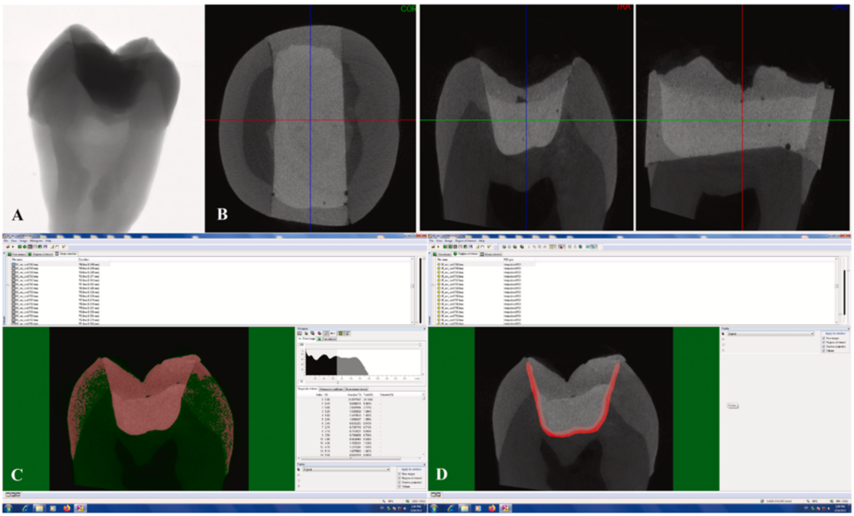


Figure 2 Workflow of 3D internal marginal adaptation analysis: raw image (A), multiplanar image sequences (B), reconstructed image (C), identification and designation of region of interest (ROI) in the axial slices (D)

Scanning electron microscopy – Internal marginal adaptation

After one month storage in physiological saline solution the roots of five restored teeth from each group were removed 2 mm below the cemento-enamel junction and the crowns were cross-sectioned through their centers in a mesio-distal direction, and one half of the teeth were further cross-sectioned horizontally, using a water-cooled diamond blade. The dentin-restoration interface was examined on the pulpal and lateral walls. The SEM image scale bar was used for calibration and the lengths of debonded segments were obtained in micrometers. Data were summed and the total unbonded interface length as a function of the total length of designated section was calculated [(unbonded length/total length) x100 = interfacial gap percentage = IG%].

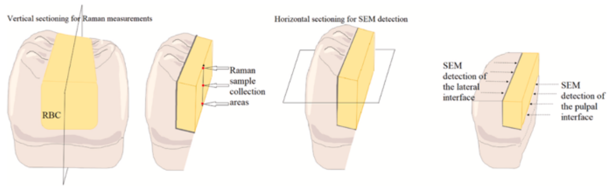


Figure 3. Schematic figure of sample preparation for micro-Raman and scanning electron microscopy (SEM) measurements. The resin-based composite (RBC) fills the cavity which has exactly the same width (2.5mm) and depth (5mm) occluso-proximally. Mesio-distal vertical sectioning provided the sample for the micro-Raman measurements at three different points along the occluso-

pulpal diemnsion of the RBC. Horizontal sectioning of the halves provided the sample for SEM measurements along the dentin-restoration interface at a 200 μm section of the lateral and the pulpal wall.

Micro-Raman spectroscopy measurements – degree of conversion

The vertically cross-sectioned teeth (n = 5 per group) (Fig. 3) were mounted on a universal holder that enabled translation along the sample, providing exposure at different depths to the excitation laser light. One-month post-cure degree of conversion values were evaluated with a confocal Raman spectrometer (Labram HR 800, HORIBA Jobin Yvon S.A.S., Longjumeau Cedex, France). Raman spectra were collected from three depths of the restoration: 0.5 mm below the surface (top); at the geometric center of the distance between the top and bottom of the sample (middle); and 0.5 mm occlusally from the bottom of the cavity (bottom). During the measurements, the exposed sample surface was about 0.2 mm in diameter with an integration time of 10 s.

Results

Study I Assessment of cracks in the restored teeth

Regarding the number of cracks right after the restorative procedure, a significantly lower number of polymerization-induced cracks were counted in the fiber-reinforced restorations (groups 1 and 2) than in the control group (layered RBC filling). Comparing either the non-fiber-reinforced groups (group 3 and the control group) or the SFRC groups (groups 1 and 2), the results did not indicate significant difference (Fig. 4).

As for the comparison between the two timepoints (right after the restorative procedures and 1 week post hoc) a significantly higher number of cracks were counted in all groups after a week. However, only the control group (layered RBC filling) differed significantly from all the other groups and there was no significant difference between the other groups (Fig. 5).

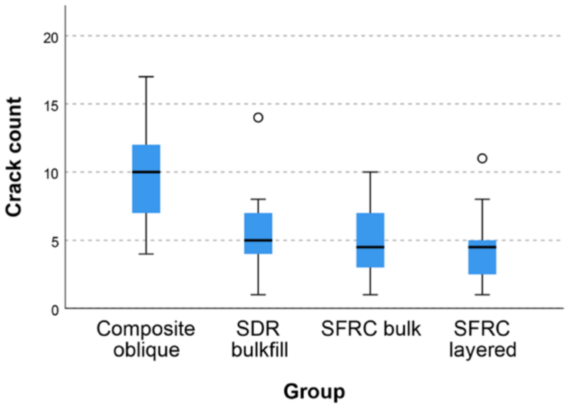


Figure 4 Box plots of the crack counts immediately after restoration

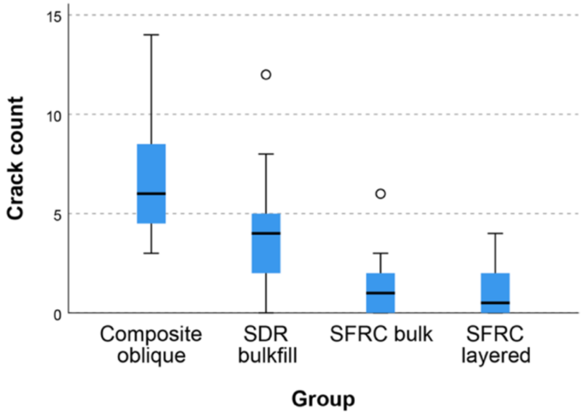


Figure 5 Box plots of the crack counts 1 week after restoration

Study II Assessment of internal adaptation and the degree of conversion

Micro-computed tomography measurement - 3D internal adaptation and porosity

The ratio of interfacial gap volume to the total interface volume is presented in Fig. 6. The largest gap formation in relation to the examined total interface was detected in the SFRC group filled with layered technique, meanwhile SDR_Bulk revealed the best internal adaptation. However, there was no statistically significant difference between the layered [EverX_Layered vs. G-aenial_Layered] and the bulk-filled groups (EverX_Bulk vs. SDR_Bulk).

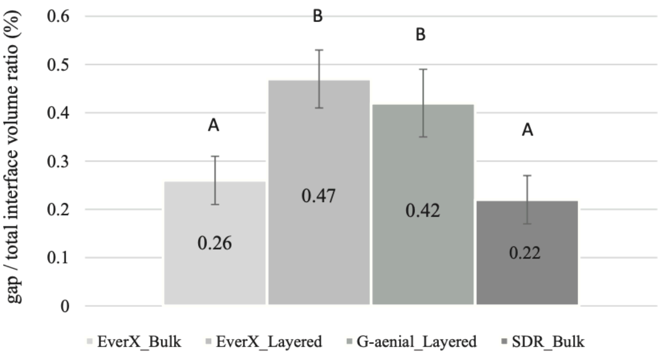


Figure 6 Ratio of interfacial gap volume to the total volume of the designated examined interfacial area (region of interest, ROI) evaluated with 3D micro-computed tomography measurements. Different capital letters indicate a statistically significant difference according to the one-way ANOVA and Tukey's post hoc tests.

Scanning electron microscopy – internal adaptation

Complementary SEM analysis of the pulpal and lateral interfaces of the dentin-RBC revealed comparable performance of the investigated RBC types and application methods on the pulpal floor, however, distinct results were visualized on the lateral walls. Interfacial defects at the pulpal interface were detected in similar length (IG% = 100%) for each investigated group. The interfacial defects mostly developed between the adhesive-RBC interface. Well sealing (IG% = 0%) internal adaptation was demonstrated at the lateral interfaces of SDR_bulk. SEM images of Ever- X_layered demonstrated 70% of IG, meanwhile G-aenial_layered and EverX_bulk groups showed 40% of gap formation along the examined lateral interfacial section. The gaps visible along the lateral walls were formed between the adhesive layer and the dentin.

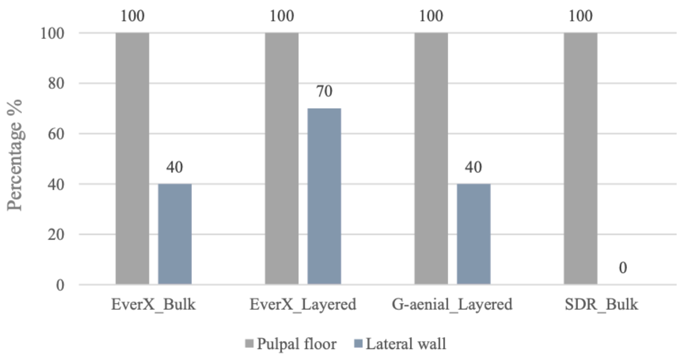


Figure 7 Interfacial gap % (gap/total measured surface) at the pulpal floor and lateral wall of the investigated cavities restored with short-fiber reinforced, conventional and flowable bulk-fill resin composites applied in bulk or incremental technique evaluated with scanning electron microscope.

Micro-Raman spectroscopy measurements – degree of conversion (DC)

Regarding the DC at the top, middle, and bottom surfaces of the samples, percentages ranged between 77.1–

90.7%, 75.9–87.8%, and 74.3–83.2%, respectively. The highest DC values were achieved by G- aenial_Layered group, while EverX_Bulk provided the lowest DC values. When comparing the DC values measured at the top, middle, and bottom of the samples, it was found that both EverX_Bulk and EverX_Layered reached almost the same degree of polymerization throughout the entire depth (Fig. 8). Statistically significant differences were found among DC% of all groups at the top and middle parts of the samples, except EverX_Bulk and EverX_Layered. At the bottom of the samples, more groups showed similar DC values, except SDR_Bulk vs. G-aenial_Layered, Ever-X_Bulk vs. G-aenial_Layered, and EverX_Layered vs. G-aenial_Layered.

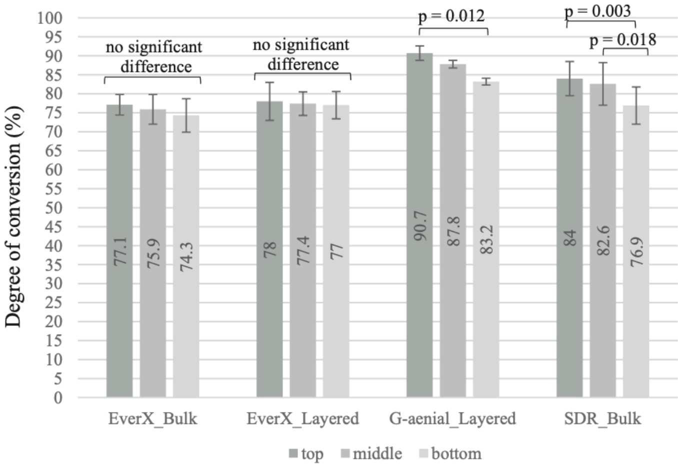


Figure 8 Differences in degree of conversion at the top, middle, and bottom region of the samples within the

investigated groups. (Comparison was performed using one-way ANOVA and Tukey's post hoc test).

Discussion and Conclusion and new findings indentified based on the results of the research

SFRC owes its outstanding results to its randomly arranged glass fibres, which can control polymerisation shrinkage Polymerization induced crack formation is inevitable in RBC restorations, however, the extent depends on the filling technique. The stress generated by post-polymerisation shrinkage is clearly reflected by the increased crack count after one week. When using SFRC there is no significant difference in the number of cracks when using SFRC layering and bulk-fill techniques.

Gap formation on the pulpal wall can be explained by the structure of the dentin (larger diameter of the dentin tubules), the osmosis effect of the oxygen inhibition layer on the adhesive layer and the direction of the shrinkage vector. Reduced axial wall gap formation can be observed due to a more favourable dentin structure.

Our results were measured after 1 month of storage in water and are therefore influenced by the water absorption of the RBC. The expansion of the formed cracks is more pronounced with the layering technique.

Within the limitations of this ex vivo study, it can be concluded that:

- Polymerization shrinkage stress induced material- and placement technique–dependent crack formation in tooth, which phenomenon further progressed 1 week after the restoration.
- SFRC was more resistant to shrinkage stress during the restorative procedure; however, after 1 week, besides SFRC, bulk-fill RBC also showed higher resistance to polymerization shrinkage-related crack formation than layered RBC fillings.
- SRFC can decrease the shrinkage stress-induced crack formation in MOD cavities.
- Bulk placement of RBCs exhibited lower interfacial gap volume and achieved satisfactory DC in deep cavities without significant correlation between these parameters.
- The interfacial gap and DC values were predominantly influenced by the RBC type and filling technique.
- The least interfacial detachment occurred in the teeth restored with the flowable bulk-fill RBC (SDR_Bulk). Incremental insertion of SFRC had no advantage over bulk placement in terms of IA and DC.