In vitro evaluation of direct restorations utilizing short fiber-reinforced composite without coverage.

PhD Thesis

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Publications providing the basis of the thesis:

Tarjányi, T.; **Jakab, A.G.**; Sámi, M.; Bali, K.; Rárosi, F.; Jarábik, M.L.; Braunitzer, G.; Palkovics, D.; Lassila, L.; Lempel, E.; et al. The Nanomechanical Performance and Water Uptake of a Flowable Short Fiber Composite: The Influence of Bulk and Layering Restorative Techniques. Polymers 2025, 17, 1553, doi:10.3390/polym17111553. (Q1)

Jakab, A.G.; Néma, V.; Molnár, J.; Alföldi, A.; Braunitzer, G.; Palkovics, D.; Lassila, L.; Garoushi, S.; Lempel, E.; Fráter, M. Crack Propensity of Different Fiber-Reinforced Direct Restorative Procedures in Deep MOD Cavities. Dental Materials 2025, S0109564125006669, doi:10.1016/j.dental.2025.06.010. (Q1, D1)

Jakab, A.G.; Palkovics, D.; T. Szabó, V.; Szabó, B.; Vincze-Bandi, E.; Braunitzer, G.; Lassila, L.; Vallittu, P.; Garoushi, S.; Fráter, M. Mechanical Performance of Extensive Restorations Made with Short Fiber-Reinforced Composites without Coverage: A Systematic Review of In

Vitro Studies. Polymers 2024, 16, 590, doi:10.3390/polym16050590. (Q1)

Related publications:

Fráter, M.; Grosz, J.; **Jakab, A.;** Braunitzer, G.; Tarjányi, T.; Gulyás, G.; Bali, K.; Villa-Machado, P.A.; Garoushi, S.; Forster, A. Evaluation of Microhardness of Short Fiber-Reinforced Composites inside the Root Canal after Different Light Curing Methods – An in Vitro Study. Journal of the Mechanical Behavior of Biomedical Materials 2024, 150, 106324, doi:10.1016/j.jmbbm.2023.106324.

Volom, A.; Vincze-Bandi, E.; Sáry, T.; Alleman, D.; Forster, A.; **Jakab, A.;** Braunitzer, G.; Garoushi, S.; Fráter, M. Fatigue Performance of Endodontically Treated Molars Reinforced with Different Fiber Systems. Clin Oral Invest 2023, 27, 3211–3220, doi:10.1007/s00784-023-04934-2.

List of abbreviations:

- RBC: resin based composite
- PFC: particulate filler composite
- MOD: mesio-occluso-distal
- SFRC: short fiber-reinforced composite
- ANOVA: analysis of variance

1. Introduction

One of the primary goals of restorative dentistry is to replace lost hard tissue to restore both the function and aesthetics of teeth. This is most often necessary due to caries or trauma, but non-carious tissue loss such as erosion, abrasion, attrition, and abfraction may also require treatment. In recent years, the demand for restorative treatment has also been driven by the increasing aesthetic expectations of patients; however, the primary reason for restorative treatments remain the restoration of tooth structure lost due to caries. Today, resin-based composites (RBCs) are the most widely used direct restorative materials, having largely replaced amalgam due to their tooth-colored appearance and capacity for conservative preparation. Despite their popularity, conventional particulate-filler composites (PFCs) still have limitations—most notably their brittleness, polymerization shrinkage, and relatively low fracture toughness compared to dentin. These shortcomings are particularly critical in large restorations such as the ones meant to restore deep mesio-occluso-distal (MOD) cavities, where high stress and minimal remaining tooth structure increase the risk of failure. To address these challenges, short fiber-reinforced composite (SFRC) materials were developed. These materials incorporate short E-glass fibers that enhance fracture toughness and help resist crack propagation. EverX Posterior (GC Europe) and its flowable successor, EverX Flow (GC Europe), are examples of SFRCs specifically designed to replace dentin in high-stress areas. EverX Flow combines high fiber content with ease of handling and improved wear resistance. Recent studies have shown that flowable SFRCs may even perform better when used without a covering layer of conventional PFC, contrary to earlier recommendations. Given their promising mechanical properties and clinical performance, SFRCs may represent a significant advancement in direct restorative techniques—especially for structurally compromised teeth. This thesis investigates the mechanical performance and crack behavior of flowable SFRCs in different restorative configurations, evaluating their potential as standalone restorative materials.

2. Materials and Methods

1. Study on crack propensity of different fiber-reinforced direct restorative procedures in deep MOD cavities

This in vitro study was conducted on 100 intact human mandibular third molars, extracted for orthodontic reasons. Teeth were selected with similar anatomical dimensions and stored in 0.9% saline at room temperature, used within six months of extraction.

Standardized Class II MOD cavities (5 mm depth, 2.5 mm wall thickness) were prepared using a round-end parallel diamond bur. Preparation protocols followed previous research, ensuring uniform wall thickness with digital caliper control. The cavities extended into both proximal sides with uniform width and depth. Post-preparation, teeth were screened under transillumination (D-Light Pro, GC Europe, 4.3×) for cracks; specimens with enamel cracks were excluded and replaced.

All cavities were etched with 37% phosphoric acid, followed by the application of a one-step self-etch adhesive (G-Premio Bond, GC Europe). Restorations were performed with different protocols across five experimental groups (n=20 per group). Group 1 was restored with bulk-fill EverX Flow (bulk shade), shaped according to the dentin anatomy, leaving 1 mm occlusally. The restorations were completed with an occlusal layer of the same material (dentin shade). Group 2 included a maximum 0.5 mm thick flowable PFC base (G-aenial Hiflo, GC Europe) on the occlusopulpal surface. The restorations were then finished as described in Group 1. In Group 3 the flowable PFC base also incorporated a polyethylene fiber (Ribbond Ultra, Ribbond THM) within the base. The restorations were completed as described in the previous groups. Group 4 used a hybrid technique combining flowable and packable SFRC (EverX Flow and EverX Posterior), leaving 1 mm space occlusally. The restorations were completed as described in Group 1. Group 5 was a control group using oblique-layered conventional PFC (G-aenial A′CHORD, GC Europe).

After restoration, all teeth were finished and polished, then stored in saline. Crack formation was assessed under transillumination immediately after polymerization, then at one and five weeks. Cracks ≥2 mm were recorded, noting their orientation. For all hypothesis tests involving the five groups, a significance level of $p < 0.01$ was applied, as adjusted by the Bonferroni correction to control for multiple comparisons. The assumption of normality was not met in all cases, thus non-parametric tests (Kruskal-Wallis and Friedman analysis of variance; ANOVA) were applied to analyze differences between and within groups, with post-hoc pairwise comparisons to identify specific group differences ($p < 0.05$).

2. Study on Nanomechanical Properties and Water Uptake of SFRC

This study assessed three resin composite materials: a flowable SFRC (EverX Flow), a bulk-fill PFC (SDR flow+, Dentsply Sirona), and a conventional PFC (G-aenial Posterior, GC Europe). Eighteen standard-size composite specimens were fabricated for each group using a 5 × 5 × 5 mm metallic mold (n = 18/group). The specimens were prepared with different materials and layering strategies according to five study groups. Group 1 (control group): three consecutive layers of a packable conventional PFC (G-aenial Posterior) were applied in 2 mm, 2 mm, and 1 mm thick layers, respectively. In Group 2 three consecutive layers of flowable SFRC were applied in the same manner as in Group 1. In Group 3 the same flowable SFRC material used in Group 2 was applied in a single 5 mm thick layer (bulk-fill technique). In Group 4 a flowable bulk-fill PFC material was used in the same way as described for Group 3. In Group 5 after 2 consecutive layers of flowable SFRC, it was covered with a 1 mm layer of packable PFC. After post-curing, specimens were polished with SiC abrasive papers and mounted on stainless steel holders using diluted optical adhesive.

Nanomechanical surface properties were tested using a Berkovich diamond-tip nanoindenter (IND-1500, Semilab, Budapest). A total of 1710 static nanoindentations were performed (19 per specimen). Indents were distributed across the top, side, and bottom surfaces to assess homogeneity and depth-dependent properties. Creep behavior was measured on six specimens per group using the same device. Each specimen underwent 10 creep tests at 25 mN constant load over 300 seconds. The standard linear viscoelastic model was applied to interpret time-dependent penetration data and calculate modulus values.

For water degradation analysis, specimens were weighed before and during a 30-day water storage period. Static and creep nanoindentation tests were repeated after aging to evaluate mechanical degradation. Water uptake was calculated by measuring changes in mass over time relative to the specimen volume.

Additionally, surface morphology was characterized using scanning electron microscopy (SEM; Hitachi S-4700). Specimens were gold-coated, and large-load nanoindentations were made to aid imprint identification.

Statistical analysis was performed using SPSS v23. Normality and variance homogeneity were verified with Shapiro–Wilk and Levene's tests. Differences between groups were analyzed via one-way ANOVA with Bonferroni post hoc testing ($p < 0.05$). Viscoelastic data were modelled using least squares curve fitting.

Results

1. Crack Propensity in Deep MOD Cavities

This study investigated how different restorative approaches influence crack formation in structurally compromised teeth. At one and five weeks after restoration, significant differences were found in the total, vertical, and horizontal crack counts among the groups ($p < 0.001$). Immediately after restoration, no significant differences were observed. One week after the procedures, the control group (Group 5), restored with conventional layered PFC, showed the highest number of total cracks (mean = 6.7), while Group 1—restored with bulk-applied flowable SFRC—had the lowest (mean = 3.55) (Figure 1). Group 5 also exhibited significantly more vertical and horizontal cracks than most other groups ($p < 0.05$). The Dwass-Steel-Critchlow-Fligner post-hoc pairwise comparisons revealed significant differences in vertical crack counts between several groups. Group 5 demonstrated a significantly higher number of vertical cracks compared to Group 1, Group 3 and Group 4 ($p < 0.005$).

At five weeks, the same trend persisted. Group 5 demonstrated a significantly higher number of total cracks compared to Group 1 and Group 3 ($p < 0.05$). Additionally, group 1 showed a significantly lower number of cracks than group 4 ($p < 0.05$). The difference between Group 5 and Group 2 approached significance. Group 5 retained the highest total and vertical crack count, while Group 1 again showed the lowest values. Horizontal crack counts varied less across groups at this stage. Friedman ANOVA confirmed significant time-dependent changes in crack counts within all groups ($p < 0.001$), except for horizontal cracks in Group 2, which remained stable in the first week.

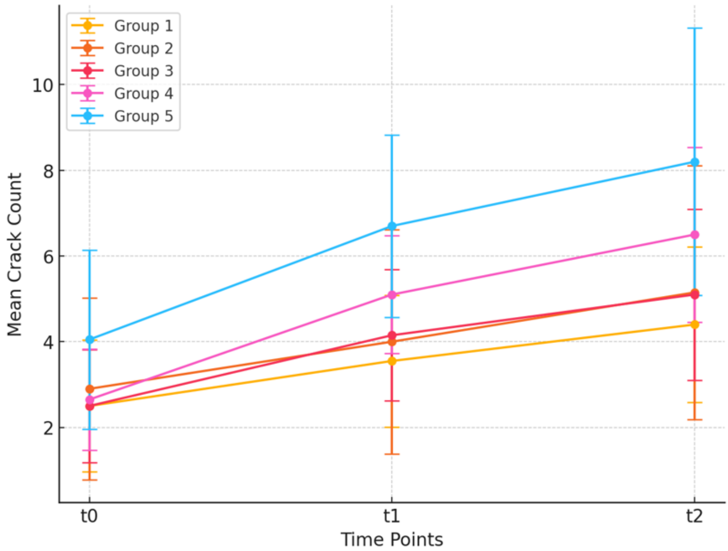

Figure 1. *Mean total crack counts across time (t0, immediately after photo-polymerization; t1, after soaking in water for one week; t2, after soaking in water for five weeks) by group. Values are shown as mean±SD.*

2. Nanomechanical Performance and Water Uptake of SFRC

The prescribed static nanoindentation measurements were conducted on the top and bottom layers of the composite specimens. Additionally, the top surface of the composite blocks was measured both before and after water storage. Static nanoindentation revealed that the bulk PFC group consistently exhibited the lowest hardness values at all layers and timepoints ($p < 0.05$). SFRC groups, particularly when used in layered or bi-structure configurations, maintained higher surface hardness even after water storage. During the creep measurements, the penetration depth (displacement) was continuously recorded over 300 s under a fixed 10 mN load. Measurements were conducted on the top layer of each group, both before and after storing the specimens in distilled water. The SFRC bulk group (Group 3) had significantly higher initial modulus (E1) and lower creep depth than bulk PFC (Group 4), both before and after water aging ($p < 0.05$) (Figure 2). Time-dependent parameters (E2 and viscosity η) also demonstrated superior performance in the SFRC groups, indicating better resistance to long-term deformation. The absorbed water mass per unit volume was compared between the groups on day 30. The bulk SFRC specimens (Group 3) exhibited a significant difference compared to all other groups, while the remaining groups showed no statistically significant differences.

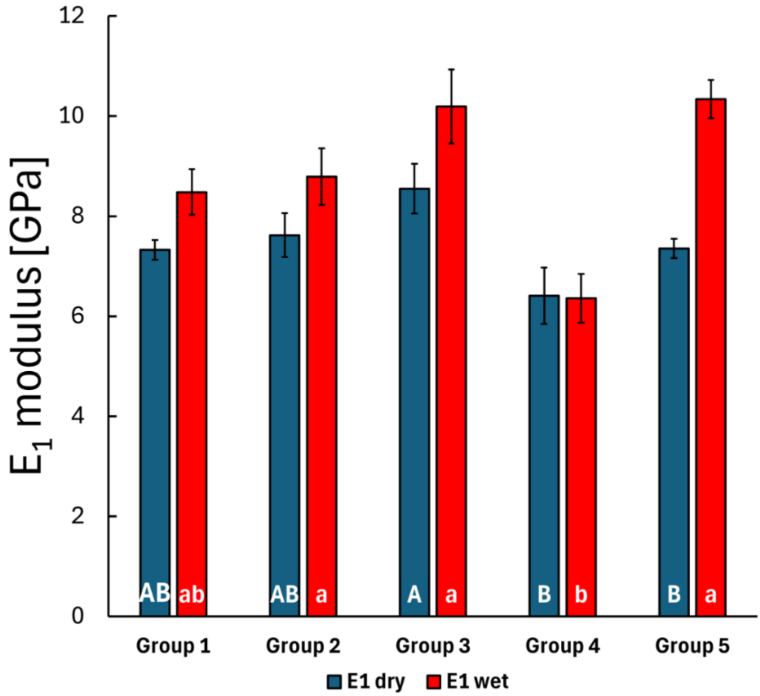

Figure 2. *The mean E_1-fitted parameter of the measured creep curves for the composite groups before and after water storage, with error bars representing the standard error of the mean. Lowercase alphabetic letters (a,b) refer to the dry groups; uppercase alphabetic letters (A,B) refer to the wet groups. Identical letters (regardless of case) indicate no significant difference, whereas different letters (irrespective of case) denote a significant difference.*

Discussion and Conclusion

Polymerization shrinkage-induced stress in RBC direct restorations remains a clinically relevant problem in dentistry due to its multiple adverse consequences. The shrinkage of RBCs due to post-cure polymerization presumably plays a role in the increase in the number of cracks observed after restorative treatment. Our results demonstrate a significant increase in the total number of cracks in all groups at both test times. In our study, direct restorations utilizing flowable SFRC without conventional PFC coverage were evaluated for crack formation, which showed significantly fewer cracks compared to conventional PFC. To better understand its overall performance, the nanomechanical properties and water uptake of flowable SFRC were also investigated. Flowable SFRC, whether applied in a layered or bulk manner, produced comparable hardness values, indicating its suitability for bulk application. The bulk application demonstrated significantly higher modulus and viscosity values, as well as better resistance to creep compared to bulk PFC.

Within the limitations of these in vitro studies and our review, it can be concluded that:

- the bulk application of flowable SFRCs reduces crack formation more effectively than conventional packable PFCs and other tested techniques.
- bulk-applied flowable SFRC exhibited superior mechanical behavior and significantly lower water absorption compared to conventional and bulk-fill PFCs.
- our findings support the use of flowable SFRC (EverX Flow) as a standalone restorative material without the need for covering.
- bulk-applied flowable SFRC showed the most favorable combination of mechanical strength and water resistance among the tested groups.