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Microleakage Assessment of Bulk-Fill Composites in Primary Molars Using Micro-CT Analysis

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Abstract

Objective: This study aimed to evaluate and compare the microleakage of different bulk-fill restorative materials in Class II cavities of primary molars using high-resolution micro-computed tomography (micro-CT).
Materials and Methods: Fifty standardized mesio-occlusal and disto-occlusal Class II cavities were prepared and restored in extracted, intact primary molars using five restorative materials: SDR, Tetric EvoCeram Bulk-Fill, VisCalor Bulk, Cention N, and Dyract XP. All restorations were finished, polished, and subjected to thermocycling of 1000 cycles. Microleakage was assessed via silver nitrate dye penetration and quantified using micro-CT imaging. The microleakage was analyzed using one-way ANOVA with Tukey's test applied for pairwise comparisons. The significance threshold was established at 5% ($p = 0.05$).
Results: All tested materials demonstrated similar microleakage patterns, with mean penetration ratios ranging from 0.569 to 0.673. No statistically significant differences were found among the five groups ($p>0.05$).
Conclusion: All tested bulk-fill materials exhibited comparable microleakage performance in primary molars. The results suggest that when proper adhesive protocols and techniques are followed, modern bulk-fill composites, including thermoviscous and alkasite materials, can provide effective marginal sealing in pediatric restorative procedures.

Keywords: Microleakage, Bulk-fill composites, Primary molars, Micro-CT, Cention N, VisCalor, SDR

Introduction

Composite materials are widely used in aesthetic dental restorations due to their excellent mechanical and tribological properties (1, 2). However, their application is technique-sensitive and ideally requires rubber dam isolation (1), which can be challenging in primary teeth and pediatric patients. A significant drawback of resin-based composites is polymerization shrinkage, which can lead to microleakage at restoration margins, increasing the risk of secondary caries. This issue is particularly important in Class II cavities in primary teeth, where the cervical enamel is thin and the enamel rods are oriented occlusally, which complicates adhesion and marginal adaptation (3). The conventional technique for composite placement involves applying the material in layers (4). Each layer should be no thicker than 2 mm due to limitations in polymerization depth and the need to manage shrinkage stress. Thicker layers result in incomplete polymerization, compromising the

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material's mechanical and biological properties (5). Curing time varies from 10 to 40 seconds, depending on the intensity of the curing light, the composite's color, transparency, and the type and concentration of the photoinitiator. This layering technique is time-consuming, risks incorporating air voids between layers, and demands significant clinical skill (6).

The development of bulk-fill composites presents a solution to the challenges associated with the layering technique. These materials can be applied in thicker layers of 4–5 mm (7), reducing procedure time and the risk of technical errors, such as air voids or contamination between layers. This is particularly beneficial in pediatric dentistry, where moisture control and rubber dam use are often difficult. Bulk-fill composites are available in low-, medium-, and high-viscosity forms, as well as two-phase systems (8, 9). Studies have demonstrated that bulk-fill composites exhibit lower polymerization shrinkage and improved marginal adaptation compared to traditional composites (10-13). However, high polymerization shrinkage in some bulk-fill materials can still cause microleakage, secondary caries, marginal discoloration, tooth or restoration fractures, and postoperative sensitivity (9). Manufacturers claim that bulk-fill composites have lower shrinkage than conventional composites (9).

Thermoviscous bulk-fill composites are also gaining popularity. These highly viscous materials at room temperature become flowable when heated to 68°C in a composite heater or a specialized heated dispenser (thermo-viscous technology). This preheating is expected to enhance the mechanical and physical properties of these composites compared to conventional composites, a hypothesis supported by published studies (14). Additionally, a novel powder-liquid bulk-fill composite based on resin and alkaline fillers (alkasite) has been developed (15). This bioactive material exhibits low polymerization shrinkage, releases significant amounts of fluoride and calcium ions at low pH, and promotes mineral deposition as calcium phosphate and calcium fluoride (15). Studies indicate that this alkasite material shows the least microleakage compared to other composites (16), making it a promising option for pediatric restorations.

The clinical consequences of polymerization shrinkage include microleakage, marginal discoloration, postoperative sensitivity, and secondary caries. Microleakage, a critical factor affecting restoration longevity, occurs when polymerization shrinkage exceeds the bond strength, resulting in microgaps at the enamel-restoration interface.

Aim

The aim of this study was therefore to evaluate the microleakage of bulk fill restorative materials using a microCT.

Material and methods

Selection and preparation of the samples

The study involved 50 primary molars that were extracted just before their physiological time for exfoliation. All parents signed an informed consent to provide the extracted tooth for the study after

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its purpose was explained to them. The Ethics Committee of the Medical University of Sofia KENIMUS granted approval for the study procedures (Approval protocol №17/24.06.2024).
Following extraction, the crowns were cleaned with hydrogen peroxide and stored in a 1% thymol solution until the study commenced. Before the start of the study the teeth were cleaned using a pressurized sodium bicarbonate suspension (PROPHYflex 3, KaVo, Biberach, Germany) and rinsed with an air/water syringe to remove debris and contaminants. The teeth were then anonymized and randomized. The inclusion criteria were as follow: healthy teeth without pathological changes, fractures, existing fillings, defects, or carious lesions, and with an intact clinical crown.
A single clinician prepared two standardized Class II cavities (mesio-occlusal and disto-occlusal) on each molar, each measuring 3 mm (bucco-oral), 4 mm (occluso-gingival), and 2 mm (mesio-distal). Cavities were created using a high-speed handpiece with water cooling and a 125 µm abrasive diamond cylindrical bur with a flat tip and rounded edges (Strauss Diamond, FL, USA). They were finished with a 45 µm abrasive bur of the same shape (Strauss Diamond, FL, USA), with a new bur used for each cavity. The buccal and lingual walls were designed parallel to each other and perpendicular to the gingival base, as was the axial wall, with all internal edges rounded.
Transparent celluloid matrices (SuperMat Celluloid Matrices, Kerr, Kloten, Switzerland) were carefully adapted to fit snugly around each tooth for the restorations. Cavities were etched with 37% phosphoric acid for 30 seconds on enamel and 15 seconds on dentin, followed by a 30-second rinse with a water-air spray. Surfaces were dried, ensuring dentin remained hydrated. An adhesive system (Adhese Universal VivaPen, Ivoclar) was applied to the cavity with a single click of the pen, gently rubbed for 15 seconds to ensure complete coverage of edges and walls, air-thinned for 5 seconds, and polymerized with an LED curing light. For restorations involving Cention N, the adhesive protocol was omitted, and the procedure adhered strictly to the manufacturer's guidelines, including the use of the recommended primer (Centrion Primer).

The prepared specimens were divided into the following groups based on the restorative material used:

- Group 1: 10 teeth restored with SDR (Dentsply Sirona, Konstanz, Germany), a low-viscosity bulk-fill composite, applied in a single layer and light-cured for 20 seconds using a 2000 mW/cm² intensity photopolymer lamp.
- Group 2: 10 teeth restored with Tetric EvoCeram Bulk-Fill (Ivoclar Vivadent, Schaan, Liechtenstein), a high-viscosity bulk-fill composite, applied in a single layer and light-cured for 20 seconds using a 2000 mW/cm² intensity photopolymer lamp.
- Group 3: 10 teeth restored with VisCalor Bulk (VOCO, Cuxhaven, Germany), a two-phase thermoviscous bulk-fill composite, applied in a single layer using a specialized warming tip and light-cured for 20 seconds with a 2000 mW/cm² intensity photopolymer lamp.
- Group 4: 10 teeth restored with Cention N (Ivoclar Vivadent, Schaan, Liechtenstein), a bulk-fill alkasite composite, applied in a single layer and light-cured for 20 seconds using a 2000 mW/cm² intensity photopolymer lamp.
- Group 5 (Control): 10 teeth restored with Dyract XP (Dentsply Sirona, Konstanz, Germany) using layering technique.

All restorations were finished and polished using discs of progressively decreasing abrasiveness (Sof-Lex Pop-On, 3M ESPE, St. Paul, MN, USA).

DOI: 10.18044/MEDINFORM.2025123.2166 ISSUE 3, 2025

Thermocycling Procedure

To simulate the natural aging of restorative materials, the specimens underwent thermocycling using a Thermocycler SD Mechatronik apparatus. The protocol involved 1000 cycles with temperatures alternating between 5°C and 55°C, a dwell time of 30 seconds per temperature, and a 10-second transition period between cycles.

Preparation of Microleakage Testing Solution

A 50% silver nitrate ($AgNO_3$) solution was prepared as a tracer for microleakage testing. This was achieved by dissolving 50 g of silver nitrate crystals in 25 mL of distilled water. To clarify the resulting dark solution, 3–4 drops of concentrated ammonium hydroxide were added via titration until clear. The solution was then diluted to 50 mL with distilled water, yielding a 50 wt.% concentration with a pH of 9.5.

Specimen Preparation and Microleakage Testing

The restored and thermocycled specimens were coated with two layers of black nail polish, leaving the restorations and a 1 mm surrounding margin exposed. After the polish dried, the specimens were immersed in the prepared silver nitrate solution for 24 hours in complete darkness. Subsequently, the specimens were thoroughly rinsed with distilled water for 5 minutes to remove excess silver nitrate. They were then placed in a radiographic developer solution for 12 hours under fluorescent light in a darkroom to reduce diamine silver ions to metallic silver grains within microcracks at the composite-tooth interface. Following this, the specimens were rinsed again with distilled water for 1 minute.

Scanning procedure

The teeth were scanned with a SkyScan 1272 X-ray microtomograph (Bruker, Belgium) at 100 kV, 80 µA, using a 1.0-mm copper filter, 9 µm pixel size, 0.45° rotation steps over 360°, and 1000 ms exposure per projection; each scan took approximately 20 minutes. Tooth projections were reconstructed with NRecon software (v2.2.0.6, Bruker, USA).

Microleakage Analysis

Microleakage of the silver nitrate solution at the resin-dentin interface was assessed by one evaluator. The penetrated silver solution was isolated and quantified using CT-Analyser V. 1.23.01 (Bruker, Kontich, Belgium).

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Statistical methods

One-way ANOVA was used to assess the bulk-fill resin composites' mickroleakage, with Tukey's test applied for pairwise comparisons. The significance threshold was established at 5% (p = 0.05). Statistical analyses were performed using SPSS v.19.0 software (SPSS Inc., Chicago, IL, USA).

Results

Figure 1 shows the scanned specimens.

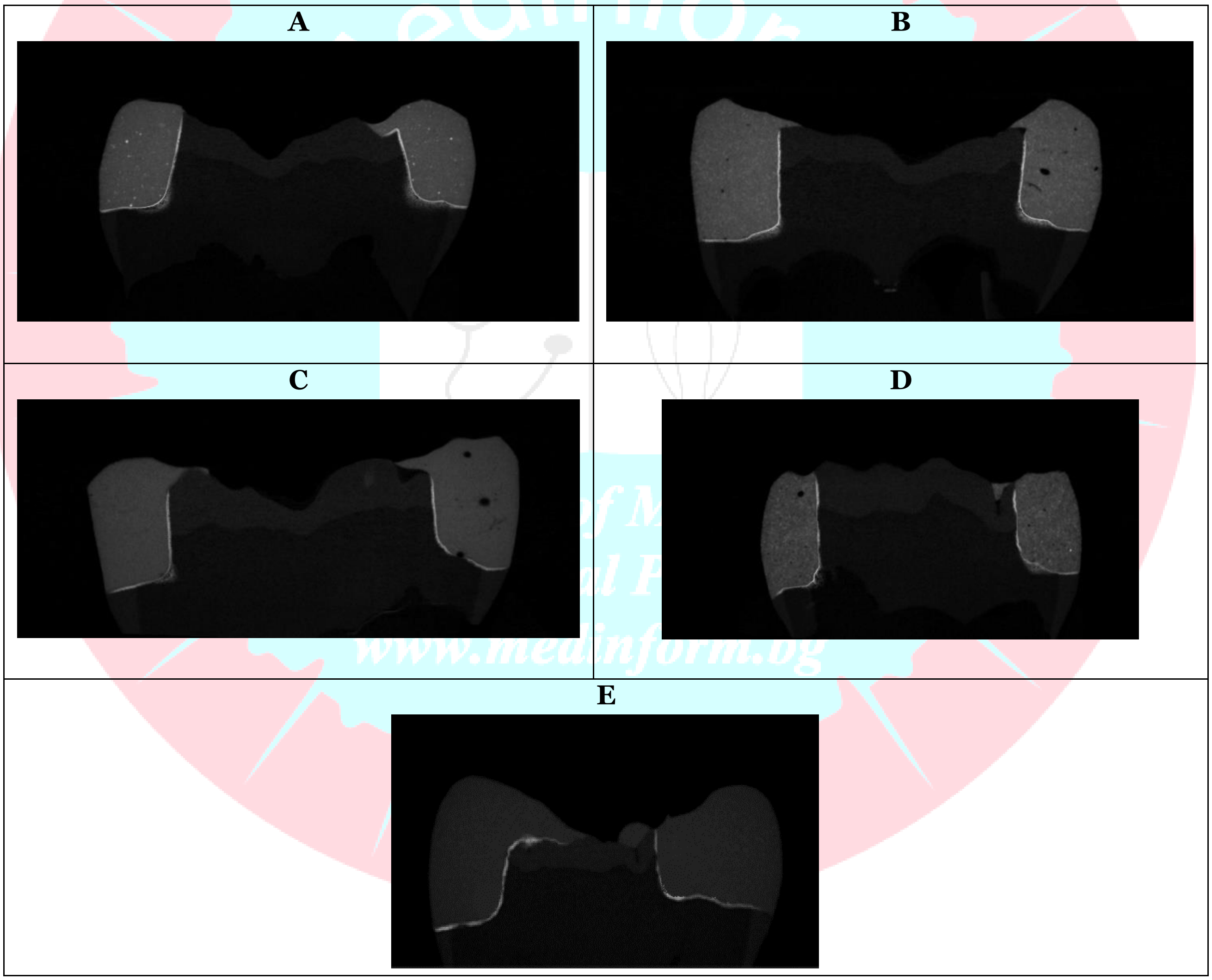

Figure 1. Infiltrated silver nitrate observed around the restorations in longitudinal section. A - SDR, B – Tetric EvoCeram, C – Viscalor, D – Cention N, E – Dyract XP

Table 1 shows the results of silver nitrate penetration ratio around the restorations.

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Table 1. Results from the mickroleackage testing

Groups	Penetration Ratio (Mean) ± SD in mm^3
SDR (1)	0.673 ± 0.204
Tetric EvoCeram Bulk-Fill (2)	0.609 ± 0.345
Viscalor bulk (3)	0.598 ± 0.248
Cention-N (4)	0.569 ± 0.205
Dyract XP (5)	0.588 ± 0.266
One-Way ANOVA	p = 0.725
Tukey's Post-Hoc Test	$p_{1,2}$=0.946, $p_{1,3}$=0.914, $p_{1,4}$=0.803, $p_{1,5}$=0.876, $p_{2,3}$=0.999, $p_{2,4}$=0.987, $p_{2,5}$=0.997, $P_{3,4}$=0.994, $p_{3,5}$=0.999, $p_{4,5}$=0.998

The results indicate no statistically significant differences in mean microleakage penetration ratios among the five restorative materials tested (SDR, Tetric EvoCeram Bulk-Fill, VisCalor Bulk, Cention N, and Dyract XP).

Discussion

Microleakage at the margins of bulk-fill composite restorations remains a critical concern in restorative dentistry, as it can lead to secondary caries, postoperative sensitivity, marginal discoloration, and compromised restoration longevity. Several studies have investigated microleakage in bulk-fill composites compared to conventional composites. For instance, a study comparing high-viscosity bulk-fill composites to conventional composites in Class II restorations found no significant differences in microleakage, regardless of gingival margin location (17). Our data align with these findings, showing no statistically significant differences in microleakage across the tested materials, suggesting comparable sealing performance among these materials under standardized conditions.
Another study evaluating ormocer- and methacrylate-based bulk-fill composites in MOD cavities reported that thinner layers (2 mm) of flowable bulk-fill composites exhibited superior marginal integrity and reduced microleakage compared to thicker layers (4 mm) (18). Our results partially diverge from this, as all tested bulk-fill composites were applied in single 4–5 mm layers, yet no significant differences in microleakage were observed across groups, possibly due to optimized adhesive protocols or material properties mitigating the effects of thicker layers. Micro-CT analyses have shown that bulk-fill composites can achieve sealing properties comparable to or better than conventional composites when proper adhesive techniques are employed (19). Our study supports this, as meticulous cavity preparation, etching, and adhesive application (except for Cention N) likely contributed to the absence of significant microleakage differences, despite the use of thicker layers. However, polymerization shrinkage remains a concern, as higher shrinkage strains can lead to delamination during setting (20).

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The clinical implications of microleakage in bulk-fill restorations are significant. Microleakage allows bacterial and fluid infiltration, promoting secondary caries at restoration margins (17, 21, 22). This can also cause pulpal irritation, resulting in postoperative sensitivity and patient discomfort (21, 22). Additionally, microleakage may lead to marginal discoloration and microcracking at the tooth-restoration interface, posing aesthetic concerns and potentially necessitating restoration replacement (17). Studies indicate that microleakage is more pronounced at the gingival base, particularly when margins are in dentin rather than enamel, compromising marginal integrity (17, 21). Over time, adhesive bond degradation due to microleakage can reduce restoration durability and increase fracture risk under functional loads (23). Our findings suggest that the tested materials, including Cention N with its bioactive properties, may mitigate these risks to a comparable degree, as no material showed significantly higher microleakage.

Several factors influence microleakage in bulk-fill restorations. Polymerization shrinkage can create external voids at the tooth-restoration interface, particularly at dentin-based gingival margins (22). The choice of adhesive technique is critical, with total-etch methods generally providing better marginal sealing at enamel margins compared to self-etch techniques (19). Material composition, including resin type and filler particles, also plays a role. For example, ormocer-based composites have demonstrated better marginal integrity than methacrylate-based composites in some studies (18). While our study did not test ormocer-based materials, the low microleakage of alkasites supports the potential of advanced filler technologies in enhancing marginal adaptation.

Applying bulk-fill composites in thinner layers (2 mm) has been shown to improve marginal integrity and reduce microleakage by minimizing polymerization shrinkage stress and enhancing cavity wall adaptation (18). Incorporating a flowable liner before bulk-fill application can further reduce shrinkage stress and improve adaptation by distributing stress more evenly (24). While our protocol did not include a liner, the consistent microleakage outcomes across groups indicate that the tested materials' properties and application techniques were sufficient to limit void formation.

High-viscosity bulk-fill composites, such as Tetric EvoCeram, often exhibit reduced shrinkage stress and better mechanical properties compared to low-viscosity options (25). Our data show higher variability in Tetric EvoCeram compared to other materials, suggesting potential challenges in achieving consistent adaptation, though not statistically significant.

Filtek™ Bulk Fill Flowable Restorative and SDR have shown superior microleakage resistance in bulk-fill restorations. Filtek exhibited the highest resistance after 20,000 thermocycles, simulating two years of intraoral conditions (26), while SDR achieved excellent marginal sealing, with 93.33% of restorations showing no dye penetration (27). In our study, SDR displayed relatively low microleakage, though not significantly different from other materials.

Cention N, a novel bulk-fill alkasite material, has shown promising results. Ali et al. found that Cention N with adhesive had significantly lower microleakage than intermediate restorative material (IRM) in pulpotomized primary molars (28). Our data align with this, as Cention N exhibited one of the lowest mean microleakage values. This suggests that Cention N's bioactive properties, including fluoride and calcium ion release, may enhance marginal sealing, even without adhesive in our protocol, though further clinical validation is needed.

VisCalor, a thermoviscous bulk-fill composite, also demonstrates low microleakage when preheated. Yang et al. reported that preheating VisCalor at 68°C for 30 seconds or 3 minutes did

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not increase polymerization shrinkage or compromise kinetics, preserving marginal integrity (29). Our results for VisCalor support this, showing comparable microleakage to other materials, likely due to enhanced cavity adaptation from preheating, even in 4–5 mm layers.

Conclusion

Effective adhesive techniques, material selection, and application protocols are critical for minimizing microleakage in bulk-fill restorations. Our findings show that bulk-fill composites such as SDR, Tetric EvoCeram Bulk-Fill, VisCalor Bulk, Cention N, and compomers as Dyract XP perform similarly under standardized conditions. These results emphasize the importance of clinical technique and suggest that modern bulk-fill materials can achieve reliable marginal sealing in thicker layers when optimized protocols are applied. Further studies with larger sample sizes or extended thermocycling are recommended to explore subtle differences in material performance.

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