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Original article

MICRO-CT ANALYSIS OF MICROLEAKAGE IN BULK-FILL COMPOSITE RESTORATIONS: CONVENTIONAL PLACEMENT VERSUS STAMP TECHNIQUE

Ralitsa Bogovska-Gigova, Krasimir Hristov
Department of Pediatric Dentistry, Faculty of Dental Medicine, Medical University, Sofia, Bulgaria.

SUMMARY

Purpose: This study aimed to assess the microleakage in Class I bulk-fill composite by comparing the conventional bulk-fill technique versus the stamp technique, using micro-computed tomography.

Materials and Methods: Twenty-four caries-free permanent molars, extracted for orthodontic reasons, were prepared with standardized Class I occlusal cavities (4 mm deep, 5 mm mesiodistal, 4 mm buccolingual) and randomly assigned to two groups (n=12 each): Group 1 (conventional bulk-fill with Tetric EvoCeram Bulk Fill) and Group 2 (stamp technique with the same composite). Both groups followed the same adhesive protocol (37% phosphoric acid etching, Adhese Universal VivaPen, and light-curing at 1000 mW/cm²). Group 1 restorations were manually shaped and cured, with glycerin gel applied to eliminate the oxygen-inhibited layer, while Group 2 used a pre-restorative occlusal stamp for anatomy replication. Specimens underwent 1000 thermocycling cycles (5°C–55°C) to simulate aging, followed by immersion in a 50% silver nitrate solution for microleakage tracing. Micro-computed tomography analysis quantified silver nitrate penetration at the resin-tooth interface, and data were analyzed and compared. Non-parametric Mann-Whitney U test (á = 0.05) was used to compare the amount of penetrated tracer.

Results: Mean volume of penetrated tracer was 0.053 ± 0.031 for Group 1 and 0.057 ± 0.028 for Group 2, with no statistically significant difference ($p<0.05$).

Conclusion: Both techniques demonstrated comparable microleakage, suggesting that the stamp technique is a viable alternative for Class I restorations, offering efficient occlusal anatomy replication without compromising marginal integrity. Further in vivo studies are needed to validate clinical performance.

Key words: Microleakage, Bulk-fill composite, Stamp technique, micro-CT, Marginal integrity,

INTRODUCTION

The durability and clinical performance of resin restorations are largely determined by the capacity of adhesive systems to establish a stable seal at the tooth–composite interface. Microleakage at this junction continues to be a significant issue within restorative dentistry. It refers to the passage of bacteria, fluids, molecules, and ions between the cavity wall and the restorative material due to imperfect adhesion or marginal gaps. This phenomenon is clinically significant because it can lead to secondary caries, pulpal irritation, postoperative sensitivity, and restoration failure [1, 2]. Microleakage is influenced by several factors, including the type of restorative material, the adhesive system, cavity design, margin location (enamel vs dentin/cementum), and procedural variables such as contamination and thermocycling. The chemical composition of the restorative material and the adhesive protocol (e.g., three-step vs one-step adhesives) significantly affect marginal sealing, with three-step adhesives providing superior results for methacrylate-based composites [3, 4].

The most effective clinical methods for detecting microleakage in dental restorations are primarily in vitro and include dye penetration techniques, micro-computed tomography (micro-CT), and scanning electron microscopy (SEM) [5, 6, 7]. Among these, micro-CT is emerging as the most comprehensive and non-destructive method, allowing three-dimensional quantitative assessment of leakage throughout the entire adhesive interface, which is particularly valuable for evaluating different restorative materials and techniques. Micro-CT can detect and quantify tracer (e.g., silver nitrate) infiltration without sectioning the specimen, providing a more complete picture of leakage patterns compared to traditional two-dimensional methods [8]. Clinically, direct detection of microleakage is challenging. Marginal staining, secondary caries, and postoperative sensitivity are indirect indicators, but these are not specific or sensitive for early microleakage [9].

The conventional layering technique is time-consuming and often results in inconsistent increments, which can cause shrinkage and microleakage if errors occur during placement [10]. To address these challenges, bulk-fill composites were introduced to the dental market for use in the restorative treatment of posterior teeth. The bulk-fill technique involves placing a single increment of low-shrinkage composite resin, such as Tetric EvoCeram Bulk Fill, to fill the cavity and simultaneously model the occlusal anatomy before polymerization [10]. This approach reduces operative time, which is particularly beneficial in pediatric or time-sensitive cases. Despite concerns about increased configuration factor (C-factor)—the ratio of bonded to unbonded surfaces potentially elevating polymerization stress—modern bulk-fill composites demonstrate improved marginal integrity [11].

Microleakage around bulk-fill composite dental restorations is generally comparable to that seen with conventional resin composites, both in extent and clinical significance. Multiple in vitro studies have demonstrated that bulk-fill composites, when placed according to manufacturer instructions and with appropriate adhesive protocols, do not exhibit significantly greater microleakage than conventional composite restorations in Class I and II cavities [11-13].

Some studies suggest that flowable bulk-fills materials may show slightly higher microleakage than high-viscosity bulk-fills or conventional composites, but these differences are not consistently clinically significant [6, 14]. In high C-factor cavities, bulk-fill composites may result in less gap formation and improved fracture resistance compared to layered conventional composites [15]. Overall, bulk-fill composites are considered clinically acceptable for posterior restorations with respect to microleakage, provided that proper adhesive technique and isolation are maintained [13].

The stamp technique is a new approach in restorative dentistry. This technique involves creating a pre-occlusal matrix to replicate a tooth's original occlusal anatomy before caries removal, allowing precise composite restoration with minimal polymerization shrinkage, reduced micro-gaps, and less need for finishing procedures, thus saving time and improving restoration quality in pediatric dentistry [16].

Current studies on microleakage in dental restorations using the stamp technique are limited, but evidence indicates it does not affect microleakage compared to traditional composite methods [17]. The stamp technique is primarily designed to reproduce occlusal anatomy efficiently and is typically used with conventional resin-based composites. There is no direct evidence in the literature that the stamp technique alters microleakage compared to bulk-fill or conventional incremental placement.

PURPOSE

This study aimed to assess the microleakage of bulk-fill restorations placed using the stamp technique compared to the conventional bulk-fill technique, utilizing micro-computed tomography (microCT) for precise evaluation.

MATERIAL AND METHODS

This study used 24 caries-free third permanent molars, extracted for orthodontic reasons between November 2024 and April 2025. Post-extraction, the teeth underwent ultrasonic cleaning and pumice polishing to remove debris, then were preserved in a 0.1% thymol solution at 4°C to inhibit bacterial growth and maintain structural integrity. All procedures received approval from the Medical University of Sofia KENIMUS Ethics Committee (Approval No. 1936/08.05.2025).

Standardized Class I occlusal cavities (4 mm deep, 5 mm mesiodistal width, 4 mm buccolingual width) were prepared using a high-speed handpiece equipped with a diamond bur under continuous water cooling. The prepared teeth were then randomly divided into two groups: Group 1: Conventional bulk-fill restoration, and Group 2: Stamp technique with bulk-fill composite. Each cavity underwent etching with 37% phosphoric acid (3M™ Scotchbond™ Universal Adhesive, 3M ESPE, Athlone, Ireland) for 30 seconds on enamel and 15 seconds on dentin. The teeth were subsequently rinsed with water for 30 seconds and gently air-dried. A single layer of adhesive (Adhese Universal VivaPen, Ivoclar Vivadent, Schaan, Liechtenstein) was applied using a microapplicator and light-cured for 20 seconds with an Elipar™ Freelight 2 LED curing unit (3M ESPE, Athlone, Ireland) at an intensity of 1000 mW/cm².

Group 1: A bulk-fill composite (Tetric EvoCeram® Bulk Fill, Ivoclar Vivadent, Schaan, Liechtenstein) was applied in a single layer. The occlusal anatomy was manually shaped to mimic the natural tooth morphology and light-cured for 20 seconds. An additional 10-second polymerization was performed with glycerin gel (Cercamed, Stalowa Wola, Poland) to eliminate the oxygen-inhibited layer. The restoration was finished and polished using abrasive discs of progressively finer grit (Sof-Lex™ Pop-On, 3M ESPE, St. Paul, MN, USA).

Group 2: Pre-Restorative Stamp Creation: Before cavity preparation, an impression of the occlusal surface was created using a liquid rubber dam (Opaldam, Ultradent Products Inc., South Jordan, UT, USA) to preserve the original anatomical features. Following cavity preparation and adhesive application, a 4 mm layer of bulk-fill composite (Tetric EvoCeram® Bulk Fill, Ivoclar Vivadent, Schaan, Liechtenstein) was placed, ensuring full adaptation to the cavity walls. A thin layer of Teflon tape was applied over the composite, and the pre-made stamp was pressed onto the uncured material to replicate the occlusal anatomy. Excess composite was removed before polymerization. The restoration was light-cured for 10 seconds through the stamp using the Elipar™ Freelight 2 LED curing unit (3M ESPE, Athlone, Ireland) at 1000 mW/cm², followed by an additional 10 seconds after removing the stamp and Teflon tape.

After that, to mimic the aging process of the restorations, specimens were subjected to thermocycling using an SD Mechatronik Thermocycler (SD Mechatronik, Feldkirchen- Westerham, Germany). The process consisted of 1000 cycles alternating between 5°C and 55°C, with a 30-second dwell time at each temperature and a 10-second transition period between cycles.

A 50% silver nitrate (AgNOƒ) solution was prepared as a microleakage tracer by dissolving 50 g of silver nitrate crystals in 25 mL of distilled water. To the resulting dark solution were added 3–4 drops of concentrated ammonium hydroxide through titration until transparent, then diluted to a final volume of 50 mL with distilled water to achieve a 50 wt.% concentration and a pH of 9.5.

Following thermocycling, the restored specimens were coated with two layers of black nail polish, leaving the restoration and a 1 mm marginal area exposed. After drying, the specimens were submerged in the silver nitrate solution for 24 hours in complete darkness. They were then thoroughly rinsed with distilled water for 5 minutes to remove residual silver nitrate. Subsequently, the specimens were immersed 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 tooth-composite interface. The specimens were then rinsed again with distilled water for 1 minute.

At the end, the teeth were scanned using a SkyScan 1272 X-ray microtomograph (Bruker, Belgium) with settings of 100 kV, 80 µA, a 1.0-mm copper filter, 9 µm pixel size, 0.45° rotation steps over 360°, and a 1000 ms exposure per projection, with each scan lasting approximately 20 minutes. Projections were reconstructed using NRecon software (v2.2.0.6, Bruker, USA). A single evaluator analyzed microleakage of the silver nitrate solution at the resin-tooth interface.

Statistical methods: Statistical analysis was conducted using IBM SPSS Statistics, Version 19.0 (IBM Corp., Armonk, NY, USA). Normality of data distribution was assessed with the Shapiro–Wilk test ($p < 0.05$). The non-parametric Mann-Whitney U test was used to evaluate microleakage in bulk-fill resin composite restorations. The significance level was set at 5% (p = 0.05).

RESULTS

Figure 1 shows representative micro-CT images of the scanned specimens.

Fig. 1. Infiltrated silver nitrate observed around the restorations in longitudinal section. A – Conventional bulk-fill technique, B – Stamp technique with bulk-fill restorative material.

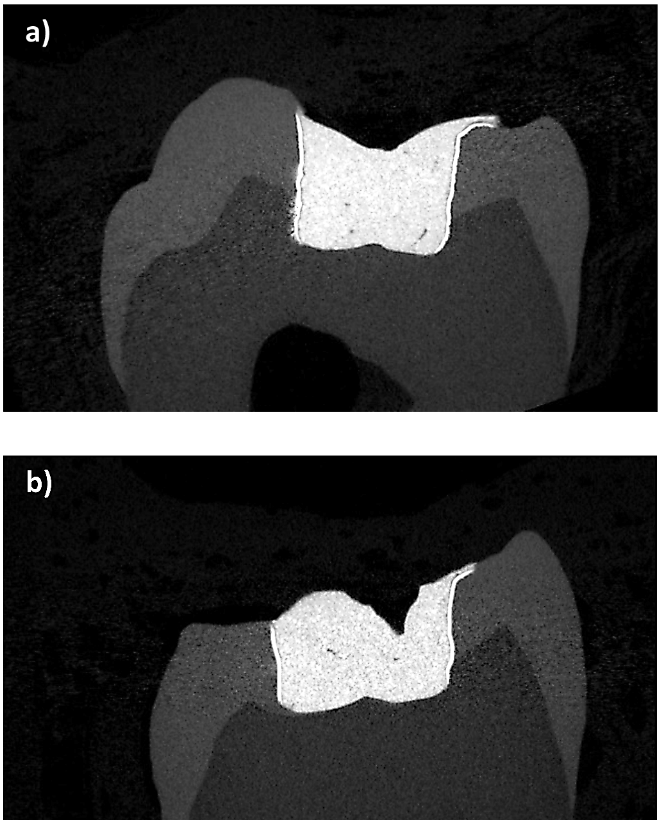

Table 1 shows the results of the silver nitrate penetration ratio around the restorations.

Table 1. Volume of silver nitrate recorded (mm3) in each group.

Groups	**Penetrated Volume (Mean) ± SD**
Group 1: Conventional bulk-fill restoration	0.053 ± 0.031
Group 2: Stamp technique with bulk-fill composite	0.057 ± 0.028
Mann-Whitney U test	$p = 0.583$

The results indicate that there were no statistically significant differences in mean microleakage penetration ratios among the two study groups (p>0.05).

DISCUSSION

The present study evaluated microleakage in bulk-fill composite restorations placed using the conventional bulk-fill technique and the stamp technique, utilizing micro-computed tomography. The results revealed no statistically significant differences in the volume penetrated tracer between Group 1 (conventional bulk-fill: 0.053 ± 0.031) and Group 2 (stamp technique with bulk-fill composite: 0.057 ± 0.028), p=0.583. The lack of significant differences suggests that the stamp technique, designed to enhance occlusal anatomy replication, does not inherently increase or decrease microleakage compared to the conventional bulk-fill restoration technique [17].

The stamp technique's ability to accurately recreate the occlusal surface, as facilitated by the pre-restorative stamp, offers clinical advantages such as reduced operative time and minimal need for post-cure adjustments [16]. This is particularly beneficial in pediatric dentistry or cases requiring efficient procedures. The current study's results suggest that the stamp technique, when used with a low-shrinkage bulk-fill composite like Tetric EvoCeram Bulk Fill, achieves marginal sealing comparable to conventional methods. The use of Teflon tape and the stamp's compressive force during polymerization may enhance adaptation at the cavity margins, potentially mitigating gap formation, though this did not translate to significantly reduced microleakage in this study.

In a recent in vitro study using 100 extracted human molars with standardized occlusal cavities, the bulk-fill technique (Group A) exhibited the lowest mean microleakage score (1.41 ± 0.878) on a 0-3 scale, where 0 indicates no infiltration, and 3 represents full-depth dentin infiltration [10]. However, no statistically significant differences were found across techniques, suggesting bulk-fill provides comparable sealing to incremental methods [10]. This aligns with evidence that modern bulk-fill materials mitigate shrinkage stresses effectively, though infiltration remains inevitable to some degree. The observed microleakage indicates that some degree of infiltration occurred in both groups, consistent with prior studies noting that microleakage is an inherent challenge in composite restorations due to polymerization shrinkage [4, 5].

A recent study evaluated the performance of Class I composite restorations using the stamp technique compared to the conventional bulk-fill method, focusing on microleakage and marginal adaptation through in vitro SEM analysis of 20 extracted teeth [18]. Results showed no statistically significant difference in microleakage between the stamp technique and conventional bulk-fill restorations (p=0.288), suggesting that the stamp technique's pressure application on the final composite layer achieves comparable marginal sealing [18]. Assessment of the microleakage around the stamp restoration technique with micro-CT is not specifically reported in the medical literature. The stamp technique itself is a relatively recent adaptation for direct composite restorations, and while it is evaluated for marginal adaptation and microleakage, the reporting follows the same conventions as other composite techniques—ordinal scores, depth in mm, or percentage of margin affected [19]. Our findings indicate that the stamp technique is a viable alternative for Class I restorations, offering efficiency in occlusal anatomy replication without compromising microleakage performance, though further in vivo studies are needed to confirm clinical applicability.

Limitations of this study include the relatively small sample size (n=24), which may have limited the statistical power to detect subtle differences in microleakage. Additionally, the in vitro nature of the study does not fully replicate intraoral conditions, such as salivary contamination or occlusal loading, which could influence clinical outcomes.

The clinical implications of these findings suggest that both the conventional bulk-fill and stamp techniques are viable options for posterior restorations, offering comparable marginal integrity when performed with meticulous adhesive protocols and isolation. The stamp technique's efficiency in replicating occlusal anatomy makes it particularly appealing for cases prioritizing time and precision, such as in pediatric patients. However, clinicians should remain vigilant about microleakage risks, as the observed penetration ratios indicate that neither technique eliminates gap formation entirely, potentially leading to secondary caries over time.

CONCLUSION

Within the limitations of this in vitro study, the conventional bulk-fill and stamp techniques exhibited comparable microleakage in Class I composite restorations. The stamp technique, leveraging a pre-restorative occlusal matrix, provides an efficient method for replicating occlusal anatomy while maintaining marginal sealing similar to conventional bulk-fill placement. These findings support the clinical applicability of the stamp technique, particularly in time-sensitive or pediatric cases, though microleakage remains an inherent challenge due to polymerization shrinkage. Larger in vivo studies are recommended to confirm these results under clinical conditions and to further explore the stamp technique's performance across diverse cavity types and composite materials.

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Address of correspondence:
Krasimir Hristov
Department of Pediatric Dentistry, Faculty of Dental Medicine, Medical University – Sofia,
1, Georgi Sofiisky str., Sofia, Bulgaria.
E-mail: k.christov@fdm.mu-sofia.bg,