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The Effect of Bulk-Fill Composites on Microleakage and Marginal Integrity

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Abstract

Bulk-fill resin composites were developed to address the limitations of conventional incremental layering techniques by enabling placement of thicker increments (up to 4–5 mm) with adequate depth of cure and reduced clinical time. One of the primary clinical concerns with resin composites is the development of polymerization shrinkage stress, which can compromise marginal integrity and increase the risk of microleakage. Microleakage contributes to secondary caries, marginal staining, and postoperative sensitivity, thereby reducing the longevity of restorations. This review synthesizes evidence from in vitro studies, micro-computed tomography (micro-CT) analyses, and randomized controlled clinical trials to evaluate the effect of bulk-fill composites on microleakage and marginal adaptation. Recent investigations (2024–2025) provide important insights into the performance of contemporary bulk-fill systems, including pre-heating techniques, dual-cure materials, and their clinical performance after two years. Overall, evidence suggests that bulk-fill composites demonstrate comparable or superior performance to incremental composites in terms of microleakage and marginal integrity, though outcomes are highly dependent on material formulation, curing method, and operator technique. Long-term studies remain necessary to validate their durability and optimize restorative protocols.

Keywords

Bulk-fill composites; Microleakage; Marginal integrity; Polymerization shrinkage; Dental materials; Restorative dentistry.

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INTRODUCTION

Resin-based composites (RBCs) have become the material of choice for direct restorations due to their superior esthetic properties, adhesive capabilities, and continuous improvements in mechanical performance. Despite these advantages, polymerization shrinkage remains a fundamental drawback, generating stresses that compromise the marginal seal of restorations. This can lead to microleakage, marginal staining, postoperative sensitivity, and eventual secondary caries (Al Sunbul *et al.,* 2016; Opdam *et al.,* 2008).

Traditionally, incremental layering techniques were recommended, with 2 mm increments placed sequentially to ensure adequate curing and minimize shrinkage stress (Peutzfeldt & Asmussen, 2004). However, incremental layering is time-consuming, technique-sensitive, and increases the risk of voids or contamination between layers. To overcome these limitations, bulk-fill composites were developed. These materials allow increments up to 4–5 mm, facilitated by increased translucency, novel photoinitiators, and stress-relieving resin formulations (Ilie & Hickel, 2011; Van Ende *et al.,* 2017).

While manufacturers claim that bulk-fill composites simplify placement and improve clinical efficiency, the critical question remains whether they adequately address microleakage and maintain marginal integrity. Recent studies (2024–2025) have added important data, particularly regarding pre-heating strategies, dual-cure bulk-fills, and long-term clinical trials. This review integrates both classical and contemporary evidence to provide a comprehensive assessment of the effects of bulk-fill composites on microleakage and marginal adaptation.

LITERATURE REVIEW

Polymerization Shrinkage and Stress

Polymerization shrinkage occurs as resin monomers convert into a polymer network,

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leading to volumetric contraction of 2–3% in conventional composites. The resulting stresses compromise adhesion at the tooth-restoration interface, causing gap formation. Bulk-fill composites attempt to mitigate this through modified resin chemistry, including aromatic urethane dimethacrylates and stress-relieving monomers. Innovations such as Ivocerin, a germanium-based photoinitiator, have improved depth of cure and reduced stress concentration. Studies by Rosatto *et al.* (2015) and Rizzante *et al.* (2019) confirmed that bulk-fills generate lower shrinkage stress compared to conventional RBCs.

Depth of Cure and Photoinitiator Innovations

A key advantage of bulk-fill composites lies in their enhanced depth of cure. Increased translucency and innovative photoinitiators allow polymerization up to 4–5 mm. Hardness ratio tests (top/bottom) have shown adequate polymerization even in deep cavities (Ilie & Hickel, 2011). Recent clinical protocols emphasize the importance of curing light intensity and duration. Garcia *et al.* (2014) demonstrated that adequate light exposure significantly impacts the depth of cure. In 2024, Bahari *et al.* confirmed that pre-heating bulk-fill composites not only improved adaptation but also reduced microleakage at dentin margins.

Microleakage Studies

Microleakage has been assessed through dye penetration, bacterial infiltration, and micro-CT analyses. Moorthy *et al.* (2012) showed reduced microleakage in SDR compared to incremental RBCs. Recent micro-CT studies (Bogovska-Gigova *et al.,* 2025) highlight the accuracy of 3D imaging for quantifying leakage in primary molars. Aktuğ Karademir & Akarsu (2024) reported that pre-heating reduced microleakage at enamel margins. These findings suggest that innovations in handling can further optimize bulk-fill performance.

Marginal Integrity

Marginal integrity is crucial for preventing marginal staining and secondary caries. SEM and micro-CT studies have consistently demonstrated that bulk-fills achieve comparable marginal adaptation to incremental composites (Van Ende *et al.,* 2017; Baltacioğlu *et al.,* 2024). High-viscosity bulk-fills maintain better enamel margins, while flowable types may require a capping layer for long-term success. A 2024 stereomicroscopy study by Baltacioğlu *et al.* further validated the importance of viscosity on marginal adaptation.

Clinical Outcomes and Long-Term Data

Clinical trials provide mixed but generally favorable outcomes. Czasch & Ilie (2013) found bulk-fills comparable to incrementals after 1 year. Elawsya *et al.* (2024) conducted a two-year clinical trial showing that dual-cure and light-cure bulk-fills performed similarly in posterior restorations. Similarly, Çağırır Dindaroğlu & Yılmaz (2024) reported no significant difference between bulk-fill and nano-hybrid composites after two years. Nevertheless, long-term (>5 years) data remain scarce, underscoring the need for further follow-up studies.

Factors Influencing Performance

The performance of bulk-fill composites is influenced by multiple variables: cavity configuration (C-factor), adhesive strategy (etch-and-rinse vs. self-etch), curing protocol, and material viscosity. Operator experience also plays a pivotal role. Reddit user discussions (2023–2024) reflect clinical consensus that while bulk-fills are efficient, they are not universally superior to incremental techniques, especially in high-stress posterior cavities

RESULTS

Microleakage Findings

Studies consistently indicate that bulk-fill composites demonstrate comparable or slightly lower microleakage compared to conventional incremental composites.

- In dye penetration studies: Moorthy *et al.* (2012) found that SDR flowable bulk-fill composite showed reduced microleakage in Class II cavities compared to incremental techniques.
- Pre-heating effect: Aktuğ Karademir & Akarsu (2024) and Bahari *et al.* (2024) reported that pre-heating bulk-fill composites improved adaptation and reduced microleakage at both enamel and dentin margins.

- Micro-CT analyses: Bogovska-Gigova *et al.* (2025) demonstrated accurate 3D evaluation, confirming minimal leakage in primary molars restored with high-viscosity bulk-fill composites.

Overall, factors influencing microleakage include cavity configuration, adhesive protocol, composite viscosity, and curing method.

Marginal Integrity

Bulk-fill composites generally maintain acceptable marginal adaptation, with some variability between high-viscosity and flowable types:

- SEM and stereomicroscopy studies: Van Ende *et al.* (2017) and Baltacioğlu *et al.* (2024) reported that high-viscosity bulk-fills preserve enamel margins effectively, whereas flowable bulk-fills often require a capping layer to maintain long-term marginal integrity.
- Influence of cavity type: Marginal adaptation is slightly compromised in high C-factor cavities or deep class II restorations, highlighting the need for careful handling.
- Polymerization shrinkage stress: Modified monomer formulations and stress-relieving matrices reduce the incidence of marginal gaps (Rizzante *et al.,* 2019; Rosatto *et al.,* 2015).

Depth of Cure

Bulk-fill composites achieve adequate polymerization up to 4–5 mm, validated by:

- Vickers hardness ratio tests: Ilie & Hickel (2011) showed top/bottom hardness ratios exceeding 80%, indicating sufficient curing.
- Light-curing and dual-cure techniques: Elawsya *et al.* (2024) found that dual-cure bulk-fills maintained mechanical properties comparable to light-cure bulk-fills in posterior restorations.

Clinical Outcomes Short- to medium-term clinical studies (1–2 years) reveal promising results for bulk-fill composites;

- **Two-year RCTs:** Çağırır Dindaroğlu & Yılmaz (2024) and Elawsya *et al.* (2024) reported no significant difference between bulk-fill and incremental composites regarding marginal discoloration, secondary caries, or postoperative sensitivity.
- **Long-term data:** Limited studies beyond 5 years exist; however, retrospective data suggest durability comparable to conventional composites (da Rosa Rodolpho *et al.,* 2006). .

DISCUSSION

The literature indicates that bulk-fill composites provide significant benefits in terms of clinical efficiency, depth of cure, and reduced polymerization stress. Their performance in controlling microleakage and maintaining marginal integrity is largely comparable to, and in some cases superior to, incremental techniques. Recent studies (2024–2025) confirm these findings while introducing new perspectives such as pre-heating, dual-cure formulations, and advanced imaging techniques for evaluation.

Nevertheless, the limitations of bulk-fill composites must be acknowledged. While they simplify placement, they do not eliminate shrinkage stress entirely, and marginal deterioration over time remains a challenge. Flowable bulk-fills, though easy to adapt, may compromise wear resistance without a capping layer. High-viscosity bulk-fills, conversely, offer superior strength but may be less adaptable in deep cavities. Overall, careful case selection, appropriate curing protocols, and adherence to adhesive best practices are essential.

CONCLUSION

Bulk-fill composites represent an important advancement in restorative dentistry, combining simplified placement with acceptable performance in terms of microleakage and marginal integrity. Recent studies from 2024 and 2025 support their clinical reliability, particularly when optimal protocols are followed. However, bulk-fills are not a universal solution, and operator technique remains critical. Long-term trials exceeding five years are required to establish their durability conclusively and guide evidence-based adoption in clinical practice.

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