Restoring Marginal Integrity in Subgingival Class II Composite Restorations: Overcoming Polymerization Shrinkage Stress Through Incremental Stratification With Bulk-Fill Flowable Liners

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Abstract. Polymerization shrinkage stress in posterior composite restorations remains a primary etiological factor in marginal gap formation, secondary caries, and postoperative sensitivity, particularly in subgingival Class II cavities where moisture control and bulk insertion are practically constrained. This study evaluated the efficacy of an incremental stratification protocol utilizing low-viscosity bulk-fill flowable liners in reducing cervical marginal microleakage compared to conventional oblique layering. Standardized Class II cavities were prepared in 60 extracted human premolars, assigned to four restorative protocols, and subjected to thermocycling, dye penetration, and micro-computed tomography (micro-CT) analysis. Results demonstrated that the flowable liner-based incremental protocol yielded statistically significant reductions in marginal gap width ($p < 0.01$) and dye penetration depth, establishing a clinically actionable approach for managing C-factor-driven interfacial stress in deep posterior restorations.

Keywords: polymerization shrinkage stress, Class II composite restoration, bulk-fill flowable liner, marginal microleakage, C-factor, incremental stratification, micro-computed tomography, subgingival cavity preparation, posterior direct restorations

Introduction

Marginal integrity in posterior composite restorations constitutes one of the most persistent and clinically consequential challenges in restorative dentistry. Despite decades of material science advancement, the volumetric contraction that accompanies free-radical photopolymerization of resin-based composites generates internal stress vectors directed toward the bonded tooth-restoration interface, predisposing it to adhesive failure, microcrack propagation, and ultimately, marginal gap formation. In the context of Class II

restorations — where the proximal box extends apically to or beyond the cementoenamel junction — these biophysical constraints are dramatically amplified by a high cavity configuration factor (C-factor), restricted adhesive substrate quality at the cervical dentin, and the near-impossibility of achieving consistent dry-field isolation in the subgingival zone. As of 2024–2026, posterior composite restorations account for the dominant share of direct restorative procedures performed globally, with epidemiological data from the FDI World Dental Federation estimating that Class I and Class II composites represent over 68% of all restorations placed annually in adults aged 18–65. Secondary caries initiated at the cervical margin of Class II restorations remains the leading cause of restoration failure within five years of placement, surpassing fracture and endodontic complications in frequency. The clinical and economic burden of this failure mode is substantial: repeated replacement cycles contribute to progressive structural tooth loss, iatrogenic pulp exposure risk, and patient-reported dissatisfaction. While numerous incremental placement strategies have been proposed to mitigate polymerization shrinkage — including oblique layering, centripetal build-up, and the use of sonic-activated composite delivery systems — each approach carries inherent trade-offs between time efficiency, technique sensitivity, and the capacity to adapt material flow to irregular cavity geometries. The emergence of low-viscosity bulk-fill flowable composites, characterized by modified photoinitiator systems, stress-relief monomers such as DX-511, and reduced filler particle density, has introduced a biologically and mechanically plausible intermediate liner phase capable of attenuating the shrinkage force transmitted to the cavity walls. However, the combinatorial effect of bulk-fill flowable liners used within a strictly incremental stratification protocol — rather than as standalone bulk-insertion materials — has not been rigorously characterized under conditions that simulate subgingival moisture challenge and cervical enamel-absent bonding substrates. This article is structured as follows: Section 2 describes the specimen preparation protocol, cavity standardization methodology, and group assignment criteria; Section 3 details the thermocycling regime, dye penetration scoring, and micro-CT acquisition parameters; Section 4 presents comparative quantitative outcomes across the four restorative protocols; and Section 5 contextualizes findings within current adhesive dentistry frameworks and proposes a clinically transferable chairside algorithm.

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