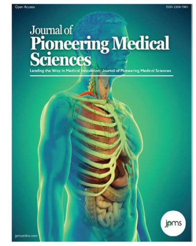

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Marginal Gap Formation in Class II Micro-Hybrid and Bulk-Fill Composite Restorations Using Different Matrix Systems

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Abstract **Objectives:** Composite resin restorations are widely used due to their favorable mechanical properties and aesthetics. However, polymerization shrinkage may compromise marginal adaptation, particularly in Class II cavities. This study evaluated the influence of Metal (MM) and Transparent Matrices (TM) on marginal gap formation in micro-hybrid and bulk-fill composite restorations. **Methods:** Forty caries-free extracted molars were randomly allocated into four groups (n = 10). Cavities were restored using either micro-hybrid composite with centripetal layering or bulk-fill composite with bulk-filling technique, combined with MM or TM (Tofflemire). Marginal adaptation was assessed using Scanning Electron Microscopy (SEM) after artificial aging and thermocycling. Statistical analysis was performed with paired and unpaired t-tests ($\alpha = 0.05$), and effect sizes were calculated. **Results:** MM groups demonstrated superior marginal adaptation in dentin (ES = 0.93, p = 0.005) and enamel (ES = 0.76, p = 0.02) compared with TM. In bulk-fill composites, matrix type showed no significant effect (p = 0.16). Micro-hybrid restorations with MM exhibited a large effect size (ES = 1.48, p<0.001) compared to TM. No significant enamel margin differences were observed between composites (p = 0.89). **Conclusion:** Matrix choice significantly influenced marginal quality in micro-hybrid restorations, but not in bulk-fill composites. Bulk-fill composites demonstrated more consistent dentin adaptation, suggesting reduced matrix dependency.

Key Words Bulk-Fill Composite Restorations, Marginal Gap Formation, Metal Matrix Band, Micro-Hybrid Composite Resin, Transparent Matrix Band

INTRODUCTION

Composite Resins (CRs) are routinely used in posterior teeth due to aesthetics and mechanical strength. Achieving optimal marginal adaptation-defined as seamless continuity at the tooth-restoration interface-is essential for long-term durability [1]. Polymerization shrinkage remains a critical challenge, particularly in Class II cavities, leading to marginal leakage and secondary caries [2]. Matrix systems play a decisive role in proximal contour and marginal integrity [3,4].

The incremental layering technique, commonly used with micro-hybrid composites, improves curing depth but increases chairside time and risk of interlayer voids [5]. Bulk-fill composites were introduced to simplify placement by allowing 4 mm increments, reducing voids and contamination [6,7]. However, large volumes may predispose to shrinkage stress and gap formation [8].

Evidence regarding the role of MM and TM on marginal quality is limited and sometimes contradictory. While MMs may block light and compromise curing, their reflective surface may enhance cervical curing depth [9-11]. Conversely, TMs allow greater light transmission but may cause reduced polymerization in deep boxes [12,13].

Hence this study was done to compare marginal gap formation in Class II cavities restored with micro-hybrid versus bulk-fill composites using MM or TM, evaluated by SEM. Hypothesis: Matrix type and composite type significantly affect marginal adaptation in enamel and dentin.

Objectives:

- To evaluate marginal gap formation in Class II restorations restored with micro-hybrid and bulk-fill composites using metal and transparent matrices
- To compare enamel versus dentin margins for both composites and matrix types
- To assess effect sizes to determine the clinical impact of differences observed

METHODS

Numerous prior investigations on microleakage have utilised a sample size of at least 8 to 10 [14,15]. Concurrently with previous studies, this study has established an appropriate sample size of 10 per group. Forty caries-free extracted human molars were selected, cleaned, and stored in distilled water at 25°C until specimen preparation. Teeth were randomly divided into four groups (n = 10): micro-hybrid composite with Centripetal Layering (CT) versus bulk-fill composite with Bulk-Filling Technique (BFT), each restored using either a Metal Matrix (MM) or Transparent Matrix (TM) secured in a Tofflemire retainer. Self-curing resin was used to mount the teeth with occlusal surfaces parallel to the floor.

Standardized mesial and distal Class II cavities (3 × 3 × 4 mm; 1 mm below the CEJ) were prepared with cylindrical diamond burs under water spray, replaced after every five uses. Dimensions were verified with loupes, and teeth not meeting criteria were excluded. Cavities were etched with 37% phosphoric acid (enamel 30s, dentin 15s), rinsed, bonded with OptiBond FL, and light-cured. Restorations were placed incrementally (CT) or in bulk (BFT), each layer/light exposure lasting 20 s at 1020 mW/cm² (LED unit, Elipar Freelight 2). Post-curing was performed for 20 s buccally and lingually.

After finishing and polishing, specimens were stored in saline at 37°C for seven days, followed by thermocycling (2500 cycles, 5°C–55°C). Replicas were made with silicone and epoxy resin, sputter-coated with gold, and examined under SEM (100×–1000×). Marginal adaptation was expressed as the percentage of continuous margins.

One blinded, calibrated examiner (kappa = 0.85) performed measurements. Statistical analysis was conducted with SPSS v26. Enamel–dentin margins were compared using paired t-tests, while composite and matrix types were compared with unpaired t-tests. Data normality was verified using the Shapiro–Wilk test, and Bonferroni correction applied for multiple comparisons. Effect sizes (Cohen's d) were reported consistently and classified as small (<0.5), medium (0.5-0.8), or large (>0.8).

RESULTS

MMs produced markedly more continuous margins than TMs (p = 0.0002; Table 1), exhibiting a large ES of0.93 in dentin and a medium ES of 0.76 in enamel (Table 1). The bulk-fill groups (bulk-fill MM and bulk-fill TM) exhibited statistically insignificant variance between the two matrix kinds (p = 0.16). The use of BFC in conjunction with the BFT produced markedly more continuous margins in the dentin (Table 2; p = 0.04, medium effect size of 0.66. The marginal fit within enamel did not exhibit significant differences between the two materials or restoration procedures (p = 0.89) (Table 2). Nonetheless, this outcome was predominantly noted in the groups utilising the conventional micro-hybrid composite, as indicated by the statistically significant variations and substantial ES of 1.48 (Table 3) between the micro-hybrid MM and micro-hybrid TM groups (p<0.001).

Table 1: Comparisons of the Continuous Margins (%) of the Specimens Based on the Matrix Type in Enamel and Dentin

Margin location(n = 20/group)	Matrix	Mean ± SD	Median	p-value	d_{cohen}	Effect size
Enamel	MM	55.23±21.47	51.44	0.02*	0.76	Medium
	TM	37.58±24.57	38.53			
Dentine	MM	33.94±26.29	29.88	0.005*	0.93	Large
	TM	11.92±20.55	9.46			
Total (Enamel and dentine)	MM	44.585±23.88	40.24	0.0002**	0.87	Large
	TM	24.75±22.56	19.73			

*Significant; **Highly significant; MM-Metal Matrix, TM Transparent Matrix

Table 2: Comparisons of the Continuous Margins (%) of the Specimens Based on the Composite Material in Enamel and Dentin

Margin location(n = 20/group)	Filling technique	Mean ± SD	Median	p-value	d_{cohen}	Effect size
Enamel	Micro-Hybrid Composite (CT)	47.36±27.14	51.22	0.89	-	-
	Bulk-Fill Composite (BFT)	46.18±25.81	44.05			
Dentine	Micro-Hybrid Composite (CT)	15.14±19.07	18.33	0.04*	0.66	Medium
	Bulk-Fill Composite (BFT)	29.82±24.91	24.36			
Total (Enamel and dentine)	Micro-hybrid composite (CT)	31.25±23.105	40.24	0.38	-	-
	Bulk-Fill Composite (BFT)	38±25.36	19.73			

*Significant; BFT – Bulk-Fill Technique; CT-Centripetal layering technique

Table 3: Comparisons of Continuous Margins (%) of the Specimens by Margin Location, Composite Restoration and Matrix Type

Margin location (n = 10/group)	Filling technique	Mean ± SD	Median	p-value	d_{cohen}	Effect size
Enamel	Micro-Hybrid Composite - MM	66.61±24.01	62.61	0.001**	1.73	Large
	Micro-hybrid composite - TM	27.47±21.22	29.38			
Dentine	Micro-hybrid composite - MM	24.79±11.05	22.07	0.02*	1.1	Large
	Micro-hybrid composite - TM	5.44±22.21	6.79			
Total (Enamel and dentine)	Micro-hybrid composite - MM	45.7±17.53	43.22	<0.001**	1.48	Large
	Micro-hybrid composite - TM	16.455±21.715	17.83			
Enamel	Bulk-fill composite - MM	44.78±14.88	46.28	0.95	-	-
	Bulk-fill composite - TM	45.39±27.73	39.62			
Dentine	Bulk-fill composite - MM	37.81±27.73	34.11	0.18	-	-
	Bulk-fill composite - TM	22.53±21.08	19.71			
Total (Enamel and dentine)	Bulk-fill composite - MM	41.295±21.305	43.84	0.32	-	-
	Bulk-fill composite - TM	33.96±24.405	31.97			

*Significant; **Highly Significant, MM-Metal Matrix, TM-Transparent Matrix

DISCUSSION

The marginal quality of the two matrix systems did not differ in a statistically significant way. These results align with those of other investigations that compare TMs and MMs [16-19]. In the current work, the conventional micro-hybrid composite shows markedly superior marginal quality when utilised with MMs. This result pertains to earlier experiments [11,13]. One possible reason for this phenomenon is that the access cavity to the proximal box was narrower than the diameter of the light guide tip, hence obstructing certain portions of the polymerisation light when the MM was employed [9,10]. This might have diminished the shrinkage stress of the hybrid composite resin, leading to a reduction in marginal gaps [13,20,21] The impact on the Depth of Cure (DoC) appears ambiguous, as curing depth was not evaluated in the current investigation. Nonetheless, the tri-site LC method was executed to attain optimal polymerisation, as shown by Hahn *et al.* [15].In the instance of bulk Fill, this impact may be diminished due to its more effective photoinitiator, which renders the polymerisation of the material less vulnerable to decreased radiant exposure while preserving its physical qualities and ensuring enough DoC [22,23] Consequently, the matrix type does not significantly impact MG generation with the BFC in the present study.

An alternative explanation for the MM yielding increased percentages of flawless margins, particularly with the conventional nano-hybrid composite, could be that its reflective surface might have focused the polymerisation light within the cavity, thereby attaining superior DoC in the deeper regions of the restoration [11]. Conversely, with a TM, more light may leave the tooth while reducing the light that can reach the deeper proximal box sections, which leads to lower marginal quality and curing. This claim could not be substantiated by the measures of the currentinvestigation and could be contingent upon further research. Nevertheless, the results by Kays *et al.* [11] indicate an effect of this kind. Despite doing three-sited LC post-matrix removal to mitigate this issue, it is necessary to anticipate that the neighbouring teeth of the artificial tooth analogue and the hard tissue of the specimen tooth itself diminish light intensity during the curing of the buccal and lingual surfaces [13,24]. In contrast, the BFC may exhibit superior polymerisation compared to the conventional nano-hybrid composite owing to its highly effective photoinitiator. Nonetheless, a discernible, yet statistically insignificant, inclination was seen indicating that MMs yielded superior marginal fit in the deeper regions of BFC restorations, consistent with a previous investigation [15].

Marginal adaption is affected by several aspects, notably the viscosity and application technique of the materials, their composition, polymerisation shrinkage, and the pressures that may occur after shrinkage [25,26]. The results reported of Baltacioğlu *et al.* [1] indicate that brand-specific characteristics, as opposed to material viscosity, substantially affect the marginal adaption of the evaluated composites. The present research aimed to maintain consistency in the characteristics associated with the cavity and the restorative technique. Therefore, meticulous attention was given during cavity preparation to achieve standardised cavities. Additionally, a benchmark adhesive technology [27] was selected and utilised in complete accordance with the manufacturer's instructions to guarantee optimal adhesion, while light-curing was executed using an outstanding performance. LED curing machine, with power intensity being continually evaluated [14].

Microscopy has typically been utilised in the examination of marginal gaps. SEM necessitates intrusive sample preparation, including conductive coatings, which may introduce artefactual alterations, hence complicating interpretation [28] Although replication or critical point drying methods can mitigate desiccation artefacts, the utilisation of dependable duplicating materials for both negative and positive replication phases is essential for attaining precision at elevated magnifications. The Environmental SEM (ESEM) facilitates the analysis of hydrated, unfixed specimens' surfaces non-destructively while retaining the benefits of conventional SEM [29]. In prior research, insignificant variations were noted in the performance of Class II CR, irrespective of the matrix system employed at baseline [30] and one-year follow-up [19].

Long-term assessments are essential, as a notable rise in restoration failure rates is documented with ageing, [31,32] and the oral cavity offers a highly unfavourable setting for dental restorations to fail [33] In the initial assessments of different matrix systems notably pre-contoured, sectional, and circumferential, we eventually chose flat matrix bands as the optimal matrix system due to practical considerations, specifically considering the primary focus of this study was on marginal gap formation, as noted in the research by Hahn *et al.* [15]. The present investigation exposed Class II restorations to two artificial ageing procedures designed to replicate both extended exposure to the oral cavity's humid environment and the mechanical and thermal stresses these CRs encounter during everyday use. These difficulties may induce stress production due to cyclic, subcatastrophic mechanical loading and a discrepancy between the coefficient of thermal expansion of the CR and the dental substrate [14]. Addressing thermocycling, it has been documented that simulating one year of clinical performance necessitates 10,000 cycles, nearly quadrupling the cycles utilised in the current investigation [34].

MM significantly improved marginal adaptation in micro-hybrid restorations, aligning with prior findings [11,13,16,35]. Reflective properties may enhance cervical curing, though not directly measured in this study. In bulk-fill composites, advanced photoinitiators minimized matrix-related effects, consistent with Ilie *et al.* [22].Clinical extrapolation is limited due to *in-vitro* design, absence of mechanical loading, and reduced thermocycling cycles (<10,000). The finding that bulk-fill composites exhibit reduced matrix dependency supports their use in deep cavities, though long-term trials are required.

CONCLUSION

Metal matrices improve marginal adaptation in micro-hybrid composites, particularly at dentin margins, whereas bulk-fill composites demonstrate reduced dependency on matrix type.

Bulk-fill composites may provide superior dentin adaptation in deep Class II cavities. These results should be interpreted cautiously due to the *in-vitro* nature of the study.

Strengths

- Blinded SEM evaluation with calibrated examiner.
- Effect sizes reported alongside p-values
- Standardized cavity design and adhesive protocol
- Same specimens used for enamel and dentin comparisons

Limitations

- No power analysis (sample size may be underpowered)
- Flat matrix bands used, reducing anatomical realism
- Limited thermocycling cycles; no mechanical loading
- Single manufacturer composites used-generalizability limited
- *In-vitro* design cannot replicate full clinical conditions

Future recommendations

- Clinical studies with longer follow-up to confirm in-vitro findings
- Depth of cure analysis using spectrophotometry
- Inclusion of chewing simulation and extended thermocycling
- Comparative studies with multiple manufacturers and matrix designs

Implications for practice

- Metal matrices may be preferred with micro-hybrid composites for improved dentin margin quality
- Bulk-fill composites demonstrate consistent marginal adaptation irrespective of matrix type, suggesting greater clinical flexibility
- Clinicians should balance tighter margins (with MM) against potential contact contouring difficulties

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