Effect of Different Light-Curing Modes on Microleakage of Bulk-Fill Composite Restorations: An in Vitro Study

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Abstract: Polymerization shrinkage and microleakage remain major concerns in Class V composite restorations because they adversely affect marginal integrity and restoration longevity. This in vitro study evaluated the effect of different light-curing modes on microleakage of Class V restorations restored using different bulk-fill composite materials.

Sixty extracted human premolars were selected and standardized Class V cavities were prepared on the buccal surfaces. Samples were restored using 3M Filtek Bulk Fill, Tetric N-Ceram Bulk Fill, and Opus Bulk Fill composites. Restorations were polymerized using continuous, ramp, and pulse curing modes with an LED curing unit. Following thermocycling, specimens underwent dye penetration testing and were sectioned longitudinally for stereomicroscopic and SEM evaluation. Microleakage was assessed using standardized scoring criteria and statistically analyzed using one-way ANOVA and Tukey post hoc test.

The 3M Filtek Bulk Fill composite demonstrated the lowest mean microleakage scores, whereas Tetric N-Ceram Bulk Fill exhibited the highest leakage values. Pulse curing mode demonstrated significantly lower microleakage compared with continuous curing mode. SEM analysis revealed improved marginal adaptation and reduced interfacial gap formation in pulse-cured restorations.

Within the limitations of this study, both restorative material and curing mode significantly influenced microleakage in Class V restorations. Pulse curing mode demonstrated superior marginal adaptation compared with continuous curing mode, while 3M Filtek Bulk Fill showed the best overall performance.

Keywords: *Bulk-Fill Composite, Microleakage, Class V Restoration, Light-Curing Modes, Polymerization Shrinkage, Marginal Adaptation.*

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I. INTRODUCTION

Composite resin restorations are currently among the most widely used restorative materials in modern dentistry because of their excellent esthetic characteristics, adhesive bonding capability, and ability to preserve sound tooth structure. Technological advancements in filler systems, resin matrices, adhesive systems, and light-curing units have considerably improved the clinical success of resin-based restorations. However, polymerization shrinkage continues to remain a major challenge associated with composite resin restorations.

Polymerization shrinkage occurs during the conversion of resin monomers into a highly cross-linked polymer network. During this process, volumetric contraction generates stresses at the bonded tooth-restoration interface. When these stresses exceed the bond strength of the adhesive system, marginal gaps are formed, allowing ingress of bacteria, oral fluids, and debris. This phenomenon, known as microleakage, may result in postoperative sensitivity, recurrent caries, marginal staining, pulpal irritation, and eventual restoration failure.

Class V restorations are especially vulnerable to marginal leakage because of their unique anatomical and structural characteristics. These restorations are frequently located in the cervical region of the tooth, where dentin and cementum margins predominate. Adhesion to cervical dentin is less predictable than enamel bonding because of increased tubular density, greater organic content, and outward dentinal fluid flow. In addition, Class V cavities exhibit a relatively high configuration factor (C-factor), which increases polymerization contraction stress during curing.

The mode of light curing plays a crucial role in determining polymerization kinetics and stress generation within composite restorations. Conventional continuous curing exposes the composite resin to constant high-intensity irradiance, resulting in rapid polymerization and early gelation. This rapid polymerization restricts viscous flow during the pre-gel phase and increases stress concentration at the adhesive interface.

To overcome these limitations, modified curing techniques such as ramp curing and pulse curing have been introduced. Ramp curing gradually increases light intensity during polymerization, while pulse curing involves delivery of an initial low-energy pulse followed by a delay period before final polymerization. These stress-modulated curing techniques prolong the pre-gel phase and permit stress relaxation before the composite reaches rigidity.

Bulk-fill composite resins have recently gained popularity because they permit placement in larger increments while maintaining adequate depth of cure and improved handling characteristics. However, the behavior of bulk-fill composites under different curing protocols remains an area of clinical importance.

Therefore, the present study was undertaken to evaluate and compare the effect of different light-curing protocols on microleakage of Class V restorations restored with different bulk-fill composite restorative materials.

II. MATERIALS AND METHODS

The present in vitro experimental study was conducted using sixty extracted human premolars obtained for orthodontic or periodontal reasons. Teeth with caries, fractures, restorations, developmental defects, or structural abnormalities were excluded from the study.

Following extraction, the teeth were cleaned of debris and soft tissue remnants using ultrasonic scalers. The specimens were disinfected in 1% sodium hypochlorite solution and stored in normal saline at room temperature until use.

Standardized Class V cavities were prepared on the buccal surfaces of all teeth using a straight diamond bur mounted on a high-speed air rotor handpiece under continuous water coolant. The dimensions of each cavity were standardized at approximately 2 mm mesiodistally, 1 mm occlusogingivally, and 2 mm in depth. Cavity dimensions were verified using a calibrated periodontal probe.

The restorative materials used in the study included:

- 3M Filtek Bulk Fill Composite
- Tetric N-Ceram Bulk Fill Composite
- Opus Bulk Fill Composite

All cavities were treated using Single Bond Universal adhesive according to the manufacturer’s instructions. The adhesive was applied using a disposable microbrush, gently air thinned, and light cured.

The prepared cavities were restored using the designated bulk-fill composite material and cured using one of the following LED curing protocols:

- Continuous curing mode
- Ramp curing mode
- Pulse curing mode

In continuous curing mode, the composite was exposed to constant high-intensity irradiance throughout the curing cycle. Ramp curing involved gradual increase in irradiance from low intensity to maximum intensity. Pulse curing involved an initial low-energy pulse followed by a delay period and final high-intensity curing cycle.

After restoration, all specimens were subjected to thermocycling to simulate thermal changes occurring intraorally. The specimens were alternately immersed in hot and cold water baths for repeated cycles.

The teeth were covered with aluminium foil completely, and a window was created using scalpel around the restoration. Specimens were then immersed in dye solution for 4 hours.

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Following dye immersion, the teeth were sectioned longitudinally using a diamond disc under water coolant. The sectioned specimens were examined under stereomicroscope and scanning electron microscope (SEM) to evaluate marginal leakage.

Table 1 Microleakage was Assessed Using the Following Scoring Criteria:

Score	Interpretation
0	No dye penetration
1	Dye penetration involving less than half of cavity wall
2	Dye penetration extending beyond half of cavity wall
3	Dye penetration reaching axial wall
4	Dye penetration extending beyond axial wall

The obtained data were subjected to statistical analysis using one-way ANOVA and Tukey post hoc test. Statistical significance was established at $p < 0.05$.

III. RESULTS

The findings of the present study demonstrated that both restorative material and curing protocol significantly influenced microleakage in Class V composite restorations.

Among the restorative materials evaluated, 3M Filtek Bulk Fill composite demonstrated the lowest mean microleakage scores, indicating superior marginal adaptation and sealing ability. Tetric N-Ceram Bulk Fill exhibited comparatively higher leakage values, whereas Opus Bulk Fill demonstrated intermediate performance.

Regarding curing protocols, pulse curing mode demonstrated the least microleakage, followed by ramp curing. Continuous curing mode demonstrated the highest degree of dye penetration and interfacial disruption.

SEM analysis revealed smoother restoration margins and reduced interfacial gaps in pulse-cured restorations. In contrast, restorations polymerized using continuous curing demonstrated more pronounced marginal defects and interfacial separation.

Table 2 The Mean Microleakage Scores are Presented Below:

Group	Material	Curing Mode	Mean ± SD
G1	3M Filtek Bulk Fill	Continuous	3.00 ± 0.72
G2	3M Filtek Bulk Fill	Ramp	1.20 ± 0.41
G3	3M Filtek Bulk Fill	Pulse	1.00 ± 0.52
G4	Tetric N-Ceram Bulk Fill	Continuous	3.40 ± 0.68
G5	Tetric N-Ceram Bulk Fill	Ramp	2.10 ± 0.56
G6	Tetric N-Ceram Bulk Fill	Pulse	1.90 ± 0.61
G7	Opus Bulk Fill	Continuous	2.90 ± 0.70
G8	Opus Bulk Fill	Ramp	1.80 ± 0.49
G9	Opus Bulk Fill	Pulse	1.50 ± 0.50

One-way ANOVA revealed statistically significant differences among the groups ($p < 0.05$). Tukey post hoc analysis confirmed significant differences between pulse curing and continuous curing protocols.

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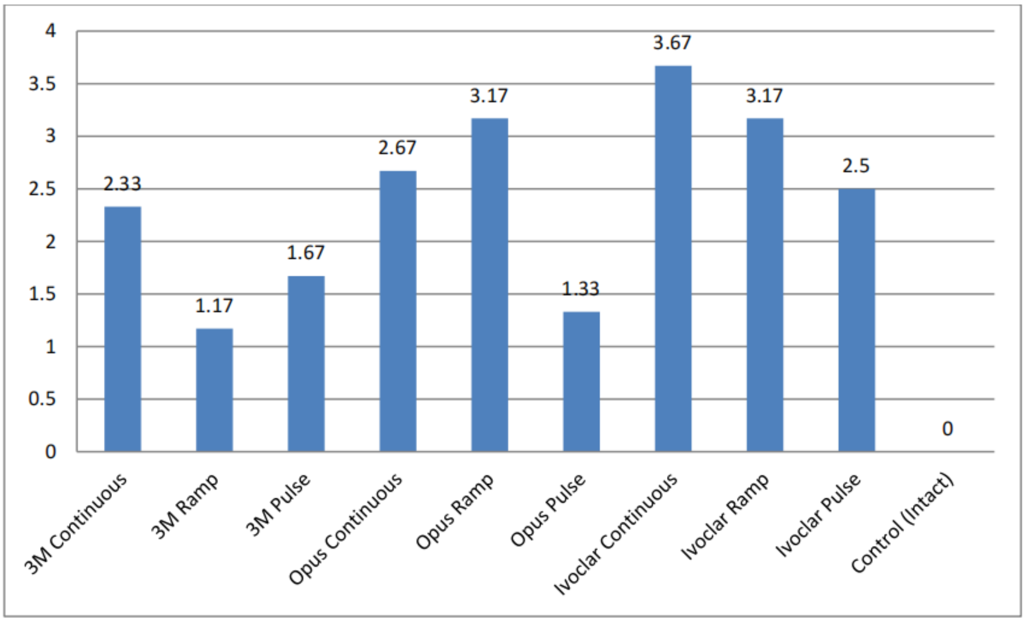

Graph 1: Statistics of Microleakage Scores in Different Experimental Groups

IV. DISCUSSION

The longevity of resin composite restorations largely depends on the integrity of the tooth-restoration interface. Despite considerable improvements in restorative materials, polymerization shrinkage continues to compromise marginal sealing by generating contraction stresses during resin curing. When these stresses exceed the adhesive bond strength, interfacial gaps may develop, facilitating the ingress of bacteria, oral fluids, and dyes, ultimately increasing the risk of postoperative sensitivity, marginal staining, and secondary caries. The present study investigated whether different light-curing protocols influence the marginal sealing ability of three bulk-fill composite materials used in Class V restorations. The findings demonstrated that both the curing protocol and the restorative material significantly affected microleakage. Among the evaluated protocols, pulse curing produced the most favorable results, whereas continuous curing showed the greatest dye penetration. In addition, 3M Filtek Bulk Fill consistently exhibited lower microleakage than the other tested materials.

The superior performance of the pulse-curing protocol can be attributed to its influence on the polymerization process. Delivering an initial low-energy exposure before final curing delays the transition from the pre-gel to the post-gel phase, allowing the material to undergo limited flow while polymerization is progressing. This stress-relieving mechanism reduces contraction forces acting at the adhesive interface and helps preserve marginal adaptation. Similar observations have been reported by Kanca and Suh, who proposed pulse-delay curing as an effective strategy for minimizing polymerization stress. Braga and Ferracane also suggested that controlling polymerization kinetics allows stress relaxation without compromising the overall degree of conversion. These mechanisms explain the reduced microleakage observed with pulse curing in the present investigation.

In contrast, restorations polymerized using continuous high-intensity irradiation demonstrated significantly greater marginal leakage. Rapid polymerization accelerates gelation, restricting the composite's capacity to compensate for volumetric shrinkage through internal flow. Consequently, contraction stresses are transferred directly to the bonded interface, increasing the possibility of adhesive disruption and gap formation. These findings are consistent with those reported by Alomari et al., who demonstrated that conventional curing protocols generate greater polymerization stresses, particularly in cavities with a high configuration factor. Likewise, Hardan et al., Chandurkar et al., and Yap and Soh observed improved marginal integrity when modified curing protocols were employed instead of continuous light exposure.

Material composition also influenced the sealing performance observed in this study. 3M Filtek Bulk Fill exhibited the lowest mean microleakage values irrespective of the curing protocol used. This favorable behavior may be related to its advanced resin matrix formulation, optimized filler characteristics, and stress-reducing monomer technology, all of which are designed to limit polymerization shrinkage while maintaining adequate mechanical properties and depth of cure. Previous studies evaluating contemporary bulk-fill composites have similarly reported improved marginal adaptation for materials incorporating modified resin chemistries and enhanced filler systems.

Among the evaluated restorative materials, Tetric N-Ceram Bulk Fill demonstrated the highest microleakage values. Although this composite has been shown to provide satisfactory mechanical performance and adequate curing depth, variations in filler loading, resin matrix composition,

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and photoinitiator systems may influence polymerization behavior and contraction stress. Differences in these material characteristics have previously been identified as important determinants of marginal adaptation and shrinkage stress. Opus Bulk Fill demonstrated intermediate performance, suggesting that although it performs satisfactorily under clinical conditions, its formulation may not provide the same stress-relieving capacity as that observed with Filtek Bulk Fill.

The stereomicroscopic findings were further supported by scanning electron microscopic evaluation. Specimens polymerized using pulse curing exhibited more continuous restoration margins with fewer interfacial defects, whereas continuously cured restorations displayed wider marginal gaps and greater disruption along the adhesive interface. These observations reinforce the concept that reducing polymerization stress contributes directly to improved marginal adaptation. Comparable findings have been reported in previous SEM-based investigations evaluating different light-curing strategies and adhesive interfaces.

From a clinical perspective, the results indicate that successful composite restorations depend not only on the choice of restorative material but also on the curing protocol employed. The use of stress-modulated curing techniques may reduce polymerization-related defects and improve the marginal seal of cervical restorations, where achieving durable adhesion is particularly challenging because of the high configuration factor and dentin-dominant margins. Therefore, optimizing both material selection and curing strategy may contribute to improved long-term clinical performance.

Several limitations should be considered while interpreting the results of this investigation. The study was performed under controlled laboratory conditions and did not reproduce factors encountered in the oral environment, such as functional occlusal loading, pH fluctuations, salivary enzymes, and long-term hydrolytic degradation. Furthermore, dye penetration remains an indirect method for evaluating marginal leakage and may not completely reflect clinical performance. Future investigations incorporating mechanical fatigue, advanced imaging techniques such as micro-computed tomography, and long-term clinical evaluation would provide more comprehensive evidence regarding the effectiveness of different curing protocols in bulk-fill composite restorations.

In summary, the present findings indicate that both restorative material composition and light-curing protocol significantly influence the marginal sealing ability of Class V bulk-fill composite restorations. Pulse curing produced superior marginal adaptation compared with continuous curing, while 3M Filtek Bulk Fill consistently demonstrated the lowest microleakage among the materials evaluated. These findings support the use of stress-modulated polymerization techniques in conjunction with contemporary bulk-fill composites to enhance the longevity of adhesive restorations.

V. CONCLUSION

Within the limitations of this in vitro study, the following conclusions were drawn:

- Both restorative material and curing protocol significantly influenced microleakage in Class V restorations.
- Pulse curing mode demonstrated superior marginal adaptation compared with continuous curing mode.
- Continuous curing produced greater polymerization shrinkage stress and increased marginal leakage.
- Among the tested restorative materials, 3M Filtek Bulk Fill demonstrated the least microleakage and best marginal adaptation.
- Stress-modulated curing protocols may improve the long-term clinical success of composite restorations.

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