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Comparative evaluation of microleakage in composite restorations using different layering techniques: an in vitro study.

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Abstract

Introduction. Resin composites are widely used in restorative dentistry due to their functional and aesthetic advantages. However, contraction stress is still a significant drawback of polymerisation shrinkage, especially in cavities with high configuration factors (C-factors). This could lead to microleakage, marginal gap formation, and adhesive failure. While shrinking cannot be completely eradicated, several solutions have been devised to lessen its impacts and enhance marginal adaptation, such as alternative layering techniques. **Aim of the study.** To evaluate and compare how various composite layering methods affect microleakage. **Material and Methods.** Standardised occlusal cavities were created using thirty removed human molars and premolars. Before being used, the teeth were cleaned and stored at room temperature in distilled water. Five groups were randomly selected from the samples, each group restored using a different technique: oblique incremental, horizontal incremental, cusp build-up," stress-breaking liner" technique with oblique layering, and split-increment technique. After thermocycling, the samples were submerged in 1% methylene blue and 50% silver nitrate dye solution for 24 hours. Microleakage was evaluated using a macro magnification following sectioning. **Results**. The split-increment group had the lowest microleakage, while the horizontal incremental group had the highest. The horizontal layering technique group showed a statistically significant difference from the other groups. **Conclusions.** The performance and longevity of composite restorations are greatly impacted by layering techniques. Restorations that are long-lasting and therapeutically successful can be achieved by minimising microleakage and improving marginal adaptation through appropriate selection and application.

Keywords: polymerisation shrinkage, layering techniques, microleakage, composite restorations, marginal adaptation.

Introduction

Composites are frequently used in restorative dentistry due to their ability to satisfy both functional and aesthetic requirements. Their optical qualities contribute to aesthetically pleasing results, and their adhesive qualities enable minimally invasive cavity preparations. Composite materials are now used in a wider range of clinical applications, from anterior restorations to large posterior reconstructions that must withstand strong masticatory stresses [1,2]. Despite these benefits, polymerisation shrinkage, which causes contraction stress at the tooth–restoration interface, limits the long-term effectiveness of composite restorations [2-4]. Volumetric contraction results from polymerisation shrinkage, which happens when monomers are transformed into a rigid three-dimensional polymer network. A process known as marginal microleakage occurs when this tension exceeds the strength of the adhesive bond, creating marginal holes that let bacteria, oral fluids, and ions pass through [1,5]. Postoperative sensitivity, marginal discolouration, subsequent secondary caries, pulpal inflammation, and decreased restoration longevity have all been associated with microleakage [5,6]. Material characteristics, cavity configuration (C-factor), adhesive protocol, light-curing process, and composite placement technique all affect its magnitude [4,7].

Alternative layering techniques have been developed in response to these constraints. In order to improve stress distribution during polymerisation, oblique incremental layering was created to decrease the number of bonded cavity walls per increment. Compared to traditional horizontal placement, this method seeks to reduce contraction stress and enhance marginal sealing by positioning the composite in an inclined orientation [5,7].

Another incremental method is the cusp build-up technique, which is especially advised for Class I and II cavities and large posterior restorations. By recreating each cusp separately, this technique lessens simultaneous adhesion to opposing cavity walls and improves control over the direction of polymerisation shrinkage. It is therefore thought to be advantageous for recovering teeth with high occlusal demands that are structurally damaged [10,12].

In a comparable manner, the split-increment approach, which divides each increment into smaller segments to increase free surface area and permit more flow during polymerisation, was developed to further minimise polymerisation stress. In high C-factor cavities, this method has been linked to enhanced marginal adaptation and stress reduction [12,15].

Stress-modifying techniques, including the use of a stress-breaking liner, have been suggested in addition to mechanical placement techniques. The purpose of low-viscosity liners is to function as elastic intermediate layers that partially absorb the stress caused by polymerisation shrinkage. Their capacity to considerably minimise microleakage has been the subject of conflicting results in both laboratory and clinical trials, their efficacy is still debatable [3,11].

There is no general agreement between practitioners on the best way to reduce microleakage, even though there are several placement strategies available. While incremental and cusp-based techniques are typically chosen in deep, large, or high-stress cavities where improved marginal adaptation is required, horizontal layering is frequently utilised in everyday clinical practice due to its simplicity [1,7,10].

By restricting the volume of composite polymerised at once and improving stress distribution, several filling protocols, such as horizontal, oblique, split increment, and cusp build-up techniques, have been proposed to reduce shrinkage stress [1,3,7]. The goal of modified light-curing procedures, including soft-start or step-curing methods, is to decrease polymerisation stress and extend the pre-gel phase. No single method eliminates shrinkage-related microleakage, even though various strategies can reduce its impact [2,4,5,7]. Instead, their success relies on the composite material, increment thickness, and curing conditions.

The purpose of this study is to assess and contrast how various composite layering methods affect marginal microleakage in posterior restorations. Standardising cavity preparations on extracted teeth, applying different composite placement techniques, evaluating microleakage after thermocycling and dye penetration, and statistically comparing the outcomes were the specific goals. This study aims to improve the marginal integrity and clinical longevity of composite restorations by determining the optimal placement technique and offering evidence-based recommendations for restorative dentistry practice.

The null hypothesis was that the composite placement technique has no significant influence on the degree of marginal microleakage.

Material and methods

Thirty human premolars and molars with intact occlusal surfaces that were extracted for orthodontic or periodontal purposes were used in this in vitro investigation. To maintain tissue hydration and avoid structural changes, teeth were cleaned, the calculus and debris were removed, and kept at room temperature in distilled water (Sigma-Aldrich, St. Louis, MO, USA) until needed.

The specimens were divided into five equal groups at random (n=6). On the occlusal surfaces, standard Class I cavities with dimensions of 4 mm in depth and 3 mm in width were created. The composite layering technique was the sole difference between the groups; all restorations were performed according to the same protocol.

Using a total-etch method, acid etching was carried out for 30 seconds using 37% phosphoric acid gel (Pegasus Etchant Gel, Pegasus Dental, Bucharest, Romania). Using a typical LED curing device, a bonding agent (Adper Single Bond 2, 3M ESPE, St. Paul, MN, USA) was evenly applied for 20 seconds and then light-cured for another 20 seconds.

The following layering techniques were used to reconstruct cavities with composite resin (Filtek Z250, 3M ESPE, St. Paul, MN, USA):

- Group 1 - Horizontal layering, increments of 1–2 mm applied parallel to the cavity floor.
- Group 2 - Oblique layering, increments applied so that each layer contacts fewer cavity walls.
- Group 3 - Cusp build-up technique, incremental reconstruction of the occlusal anatomy following the cuspal contours of the tooth.
- Group 4- "Stress-breaking liner" technique with oblique layering, a layering technique like group 2, but firstly a liner (Brilliant Flow, Coltène/ Whaledent AG, Altstätten, Switzerland) was applied at the base of the cavity.
- Group 5- Split-increment technique, horizontal increments sectioned before polymerisation to introduce additional free surfaces for stress relief.

Specimens were thermocycled (5–55°C, 500 cycles) after restoration to mimic changes in oral cavity temperature. Subsequently, specimens were immersed for 24 hours in 1% methylene blue (Sigma-Aldrich, St. Louis, MO, USA) and 50% silver nitrate (Merck KGaA, Darmstadt, Germany) to visualise marginal gaps.

After washing and drying, teeth were embedded in gypsum blocks (ProDental, Bucharest, Romania) for stabilisation and sectioned buccolingually through the center of the restoration using a diamond saw (Micracut 151, Metkon Instruments, Bursa, Turkey) under water cooling.

High-resolution macro photography (Nikon D3100; Tamron 90mm macro lens) and image analysis software (Image Pro Insight) were used to evaluate microleakage. For calibration, a millimeter scale was placed next to each surface (Figure 1). Dye penetration was determined in millimeters after the software calibrated the image. Excel (Microsoft, Redmond, WA, USA) was used to tabulate the data, and Tukey's post hoc test and one-way ANOVA were used for statistical analysis to examine group differences. A 0.05 level of statistical significance was applied.

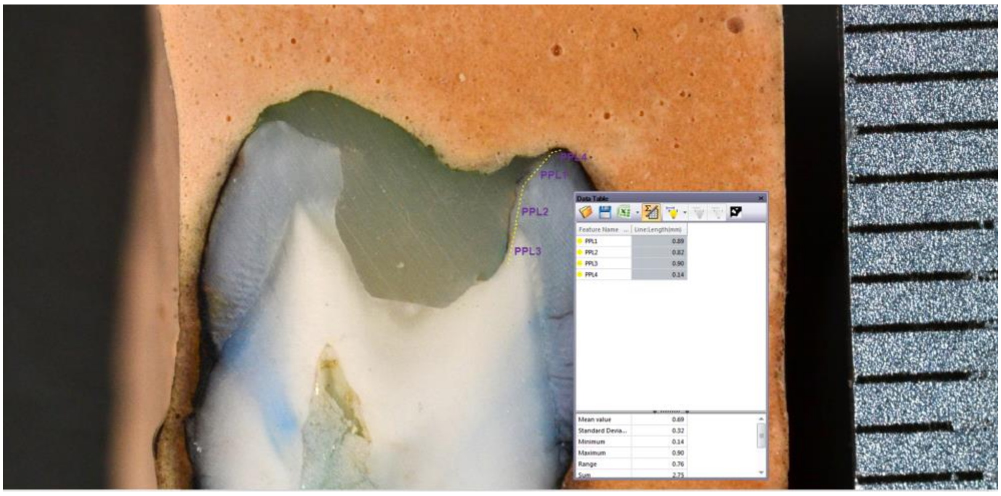

Figure 1. Representative setup for microleakage evaluation using high-resolution macro photography

Results

Marginal microleakage was observed in all five experimental groups, although the extent of dye penetration varied depending on the composite placement technique used. The highest microleakage values were recorded in the first group (dye penetration = 1.199 mm), the lowest values were observed in groups 3 and 5 (dye penetration = 0.069 mm for both). Group 2 showed lower microleakage values compared to the horizontal layering technique (group 1), however, the difference was not statistically significant ($p = 0.066$). Statistical analysis revealed significant differences between group 1 and group 3 ($p = 0.014$), and between group 1 and group 5 ($p = 0.015$). Group 4 showed lower microleakage values compared to group 5, although the difference between the two groups was not statistically significant ($p = 0.993$). These findings suggest that the composite layering technique directly influences the marginal adaptation of the restoration.

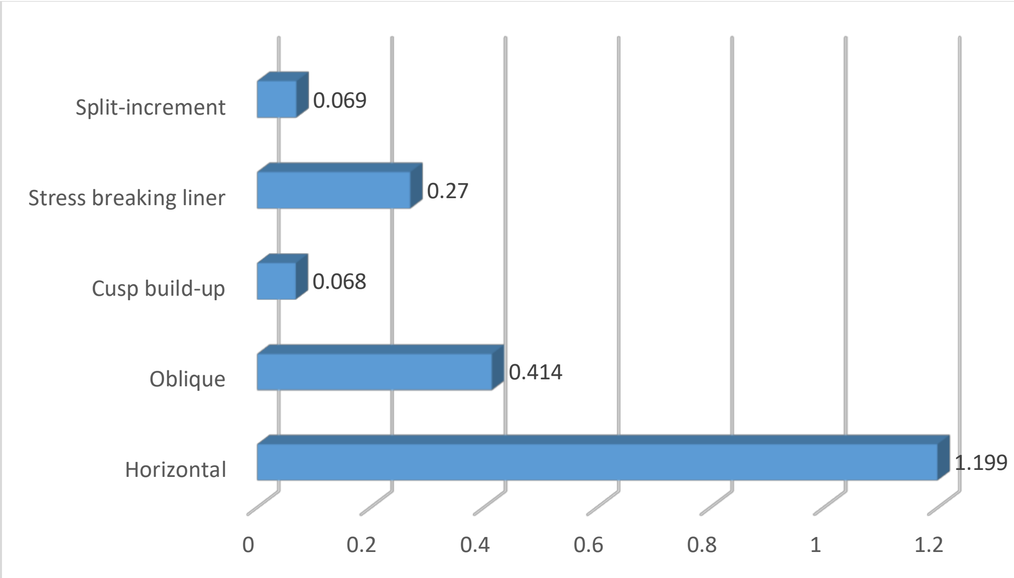

Figure 2. Mean dye penetration values (mm) for each experimental group.

Discussions

Our experimental groups all showed some degree of marginal microleakage, which is in accordance with other research showing that complete marginal sealing of resin composite restorations cannot be accomplished in vitro or in clinical settings. Polymerisation shrinkage stress, cavity configuration factor (C-factor), and restorative technique are the main factors influencing microleakage, a multifactorial process [8,9].

In the present study, the extent of microleakage varied depending on the composite placement technique. The highest dye penetration values were recorded in the horizontal layering group, while the lowest values were observed in both the cusp build-up and split-increment groups. The oblique layering group showed lower leakage than horizontal layering; however, this difference was not statistically significant. Similarly, the "stress-breaking" liner technique did not demonstrate a statistically significant improvement compared to split-increment placement. Significant differences were found only between horizontal layering and cusp build-up, as well as between horizontal layering and split-increment techniques.

Increased polymerisation shrinkage stress from simultaneous bonding to several cavity walls can be responsible for the poor performance of horizontal layering, leading to a high effective C-factor and no stress relief. As previously reported by in vitro studies [10,11], this results in the creation of interfacial gaps and enhanced marginal microleakage.

On the other hand, split-increment and cusp build-up technique groups showed better marginal adaptation. By increasing the number of unbonded surfaces and decreasing the volume of composite polymerised at one time, these techniques enable partial stress relaxation and better stress distribution throughout the repair [5,12]. By decreasing constraint at opposing cavity walls, the split-increment approach in particular may enhance stress dissipation, which has been linked to increased marginal integrity in high C-factor cavities [13,15].

Oblique layering, although theoretically advantageous due to reduced simultaneous wall contact, did not show statistically significant improvement in this study. This result is in line with earlier findings that suggest using contemporary adhesive systems and refined curing methods could reduce the discrepancies between incremental techniques. Furthermore, polymerisation kinetics and light-curing strategies have a significant impact on marginal adaptation, which may cover minor variations in placement methods [7,14,18].

Additionally, when compared to split-increment implantation, the stress-breaking liner approach did not show a discernible decrease in microleakage. The efficiency of liners as elastic stress absorbers is still controversial, especially in high C-factor cavities where bulk composite behavior rather than interfacial buffering effects dominates shrinkage stress [11,17].

Thermocycling circumstances may increase marginal deterioration by simulating intraoral thermal stresses. Over time, gap formation and dye penetration may result from differences in the thermal expansion coefficients of composite resin and tooth structure, particularly in restorations exposed to frequent temperature changes [16].

Our findings highlight that the composite insertion technique plays an important role in marginal integrity. Techniques that reduce polymerisation shrinkage stress, such as cusp build-up and split-increment layering, may improve restoration longevity by reducing postoperative sensitivity, marginal discoloration, and secondary caries risk. However, restorative success is multifactorial and also depends on adhesive system quality, composite formulation, curing protocol, and operator skill [9,18,19].

A limitation of this study is its in vitro design, which does not fully reproduce oral conditions such as occlusal loading, salivary enzymes, and long-term hydrolytic degradation. Additionally, dye penetration analysis provides only a semi-quantitative assessment of marginal leakage.

Conclusions

The findings of this in vitro investigation indicate that marginal microleakage is a complex, diverse phenomenon that has a major impact on composite restoration success.

The null hypothesis was rejected within the parameters of this investigation, and the following conclusions can be made:

1. All investigated composite insertion techniques exhibited some degree of marginal microleakage.
2. The horizontal layering method had the highest microleakage values, suggesting that it was less successful in preserving marginal integrity and reducing polymerisation shrinkage stress.
3. Although they would need more clinical time and technical sensitivity, the cusp build-up and split-increment procedures showed the lowest microleakage values and were the most successful among the studied methods in enhancing marginal adaptation.
4. The long-term clinical performance and prognosis of restorations may be negatively impacted by marginal adaptation, which is significantly influenced by the composite placement technique.
5. For direct composite restorations to last longer and reduce polymerisation shrinkage stress, an adequate incremental layering technique must be used.

Author Contributions (CRediT Taxonomy)

Conceptualisation, Methodology, Investigation, Data Curation, Writing – Original Draft, Visualisation: K.V.
Methodology, Formal Analysis: P.T.
Resources, Supervision, Validation, Writing – Review & Editing: B.K-M.
Investigation, Data Curation, Software, Project Administration, Writing – Review & Editing, Supervision: Z.B-V.

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Conflict of interest

None to declare.

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During the preparation of this manuscript, the authors used Grammarly (Grammarly Inc., San Francisco, CA, USA) to assist in improving the language clarity, grammar, and structure of the manuscript. All content was carefully reviewed and edited by the authors to ensure scientific accuracy, originality, and integrity. The authors take full responsibility for the content of the manuscript.

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