

A Comparative Evaluation of Cuspal Deflection and Cervical Microleakage among Hybrid, Microhybrid, and Nanohybrid Composite Resins in MOD Restorations: An in Vitro Study

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Abstract

Background: Polymerization shrinkage of resin-based composites remains a major concern in restorative dentistry because it may result in cuspal deflection, marginal gap formation, postoperative sensitivity, and microleakage. Advances in restorative materials such as microhybrid and nanohybrid composites have been introduced to minimize these adverse effects and improve marginal integrity.

Aim: To compare cuspal deflection and cervical microleakage associated with hybrid, microhybrid, and nanohybrid composite restorative materials in standardized mesio-occluso-distal (MOD) cavities.

Materials and Methods: Sixty extracted human maxillary premolars were selected and standardized MOD cavities were prepared. Teeth were divided into three groups according to the restorative material used: Group I - hybrid composite, Group II - microhybrid composite, and Group III - nanohybrid composite. Cuspal deflection was measured using a cuspal deflection measuring device/electronic comparator. Cervical microleakage was evaluated using dye penetration under stereomicroscopy after thermocycling. Statistical analysis was performed using one-way ANOVA and Tukey post hoc test.

Results: Nanohybrid composite demonstrated the least cuspal deflection and cervical microleakage among all groups. Hybrid composites showed maximum cuspal deflection and dye penetration. Statistically significant differences were observed between the groups ($p < 0.05$).

Conclusion: Nanohybrid composite resins exhibited superior performance with reduced polymerization shrinkage stress and microleakage compared with hybrid and microhybrid composites. Their improved filler technology and modified resin chemistry may contribute to enhanced marginal integrity and clinical longevity.

Keywords: Cuspal deflection, microleakage, nanohybrid composite, polymerization shrinkage, MOD restoration, composite resin.

Introduction

Restorative dentistry has evolved significantly with the introduction of adhesive restorative materials and advanced resin-based composites. Earlier, the primary concern of clinicians was merely the removal of carious lesions and restoration of the defect. Contemporary restorative dentistry emphasizes preservation of tooth structure, marginal adaptation, esthetics, and long-term survival of restorations [1].

One of the major limitations of composite resin restorations is polymerization shrinkage, which may generate contraction stresses at the tooth-restoration interface. These stresses can result in cuspal deflection, enamel cracks, postoperative sensitivity, marginal discoloration, secondary caries, and cervical microleakage [1,2].

Incremental placement techniques have traditionally been advocated to reduce polymerization shrinkage stresses. However, the effectiveness of incremental placement has been debated because polymerization contraction still occurs within each increment and the cumulative stress may be transferred to cavity walls [3-6].

Conventional hybrid composites containing Bis-GMA and TEGDMA resin systems are associated with higher polymerization shrinkage because of increased concentration of reactive double bonds [2,6]. To overcome these disadvantages, newer materials incorporating UDMA, Bis-EMA, nanofiller technology, and optimized resin-filler interfaces have been introduced.

Microhybrid composites improved polishability and wear resistance through incorporation of colloidal silica and fine filler particles. Nanohybrid composites further enhanced physical properties by incorporating nanosized filler particles and nanoclusters, which improved filler loading, reduced interparticle spacing, and contributed to lower polymerization contraction [3,5].

Cuspal deflection is considered an indirect measure of polymerization contraction stress. Similarly, cervical microleakage is an important indicator of marginal integrity and adhesive performance. Evaluating these parameters helps in understanding the clinical behavior of restorative materials in extensive posterior cavities [7-10].

Therefore, the present in vitro study was undertaken to compare the cuspal deflection and cervical microleakage associated with hybrid, microhybrid, and nanohybrid composite restorative materials in standardized MOD cavities.

Aim and Objectives

Aim

To compare the cuspal deflection and cervical microleakage of hybrid, microhybrid, and nanohybrid composite resins in MOD cavity restorations.

Objectives

1. To assess cuspal deflection at different stages of polymerization.
2. To evaluate cervical microleakage in restored premolar teeth.
3. To compare the performance of hybrid, microhybrid, and nanohybrid composites.
4. To determine the restorative material associated with least polymerization shrinkage stress.

Materials and Methods

Study Design

In vitro comparative experimental study.

Sample Size

Sixty extracted human maxillary premolars.

Selection Criteria

Inclusion criteria	Exclusion criteria
Intact premolars extracted for orthodontic reasons	Teeth with structural defects
Teeth free from caries, restorations, and cracks	Teeth with developmental anomalies
Teeth with sound coronal structure	Previously restored teeth

Armamentarium and Materials

Instrument / material	Manufacturer / details
Contraangled micromotor handpiece	NSK, Japan
Sectional matrix system	Palodent System, Dentsply
Composite placing instrument	Hu-Friedy
Diamond disc	Horico
Micrometer screw gauge / electronic comparator	MEDESY CE / electronic probe with D.R.O.
LED curing unit	Mectron
Hybrid composite	Herculite XRV, Kerr
Microhybrid composite	Esthet X HD, Dentsply
Nanohybrid composite	Filtek Z350 XT, 3M ESPE
Dye	Basic fuchsin
Stereomicroscope	25x magnification

Sample Preparation

All teeth were cleaned and stored in distilled water until use. Teeth were visually examined to ensure absence of caries, cracks, restorations, or developmental defects.

Standardized MOD cavities were prepared using a high-speed handpiece under water coolant. Cavity dimensions were standardized in all specimens, with an isthmus width of approximately one-third of the intercusp distance, gingival seat positioned 1 mm above the cemento-enamel junction, and standardized depth for all samples. The water bath images from the original color plate were intentionally omitted and replaced with the newly supplied procedural images.



Figure 1: Standardized mesio-occluso-distal (MOD) cavity preparation in extracted premolar specimens.



Figure 2: Tooth mounted vertically in chemically cured resin with the buccal cusp stabilized for measurement.

Grouping of Samples

Group	Restorative material	Description
Group I	Hybrid composite	Conventional posterior resin composite
Group II	Microhybrid composite	Fine particle-filled resin composite
Group III	Nanohybrid composite	Nanofiller/nanocluster-based composite

Restorative Procedure

All cavities were restored incrementally using adhesive bonding systems according to manufacturer instructions. Each increment was light cured using an LED curing unit. The incremental technique was selected to reduce polymerization contraction stress and improve adaptation to the cavity walls.

Cuspal Deflection Measurement

Cuspal deflection was measured using a cuspal deflection measuring apparatus/electronic comparator immediately after polymerization and at predetermined intervals. The palatal cusp was approximated to the receptor of the comparator and the difference in readings before and after restoration represented cuspal movement.

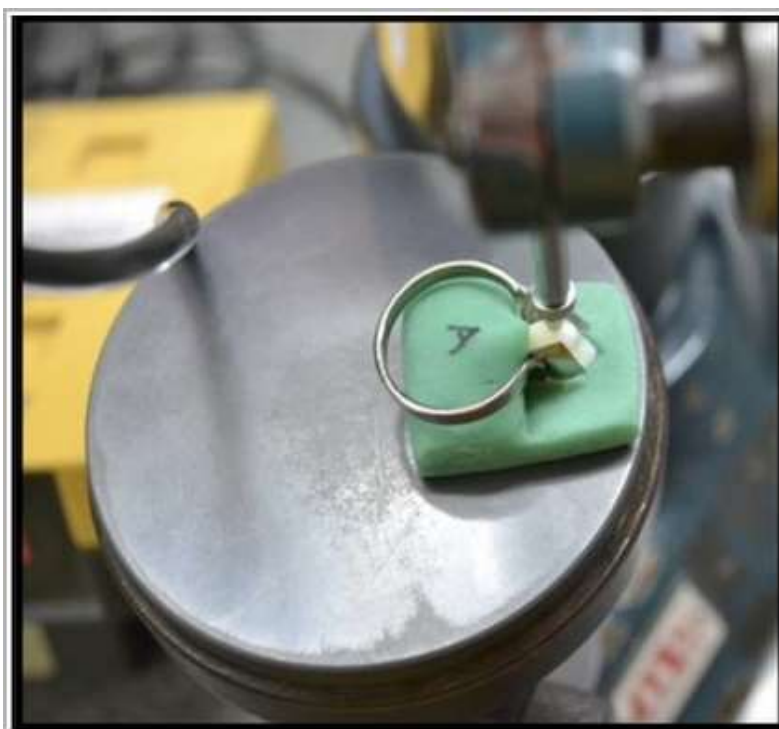


Figure 3: Palatal cusp evaluation on electronic comparator for cuspal deflection measurement.

Microleakage Evaluation

After restoration, samples were thermocycled to simulate oral thermal changes. Teeth were coated with nail varnish except for a 1 mm band around restoration margins, immersed in basic fuchsin dye for 24 hours, sectioned longitudinally, and evaluated under stereomicroscope.

The degree of cervical margin microleakage was scored based on dye penetration.

Score	Criteria
0	No dye penetration
1	Dye penetration up to half of cervical wall / superficial penetration
2	Dye penetration beyond half of cervical wall
3	Dye penetration reaching or extending along axial wall
4	Penetration into pulp chamber



Figure 4: Stereomicroscopic scoring panel for cervical margin microleakage. The water bath images have been excluded from the final manuscript.

Statistical Analysis

Data were analyzed using descriptive statistics, one-way analysis of variance (ANOVA), and Tukey post hoc test for intergroup comparison. Mean and standard deviation were calculated for cuspal deflection and microleakage scores. A p-value < 0.05 was considered statistically significant.

Results

A total of 60 extracted human maxillary premolars with standardized MOD cavity preparations were included in the present in vitro study. The specimens were randomly distributed into three experimental groups according to the restorative material used: hybrid composite, microhybrid composite, and nanohybrid composite.

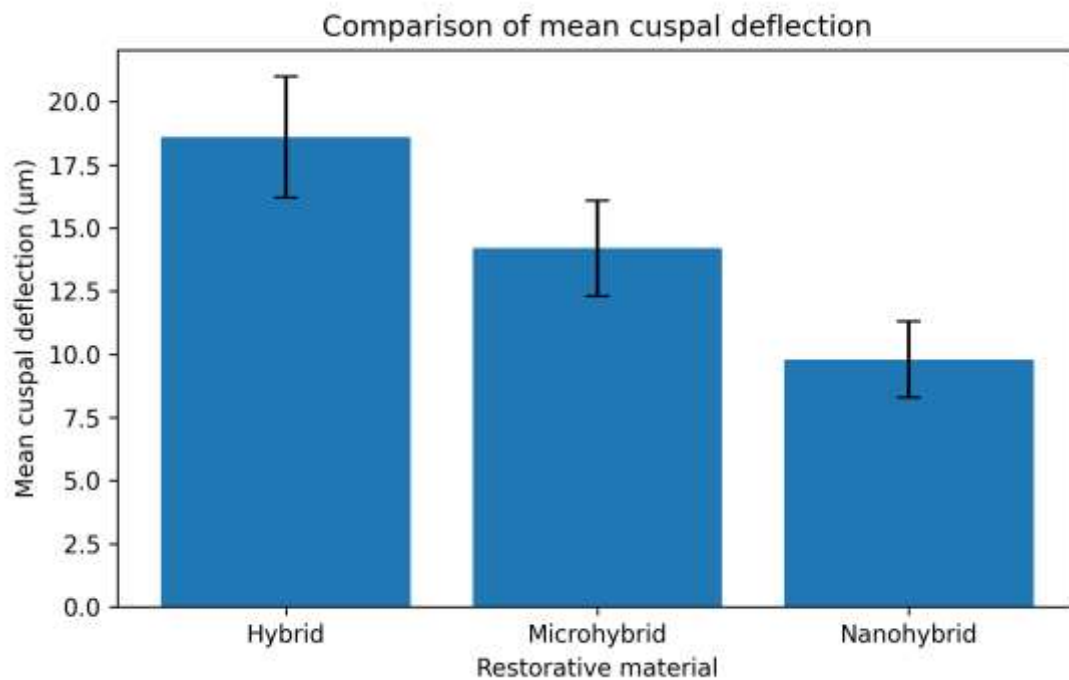
Cuspal Deflection Analysis

The mean cuspal deflection values demonstrated statistically significant differences among the three restorative groups. The hybrid composite group exhibited the highest mean cuspal deflection values (18.6 +/- 2.4 µm). During polymerization, a marked inward movement of cusps was observed immediately after light curing, indicating increased polymerization contraction stress within the cavity walls.

The microhybrid composite group demonstrated intermediate cuspal deflection values (14.2 +/- 1.9 µm). Among all groups, the nanohybrid composite group showed the least cuspal deflection (9.8 +/- 1.5 µm). Statistical analysis using one-way ANOVA revealed a significant difference between the groups (p < 0.05), and Tukey post hoc analysis demonstrated significant differences among all pairwise comparisons.

Group	Composite type	Mean cuspal deflection (µm)
Group I	Hybrid composite	18.6 +/- 2.4
Group II	Microhybrid composite	14.2 +/- 1.9
Group III	Nanohybrid composite	9.8 +/- 1.5

Table 1: Mean cuspal deflection among study groups.



Graph 1: Comparison of mean cuspal deflection among hybrid, microhybrid, and nanohybrid composite groups.

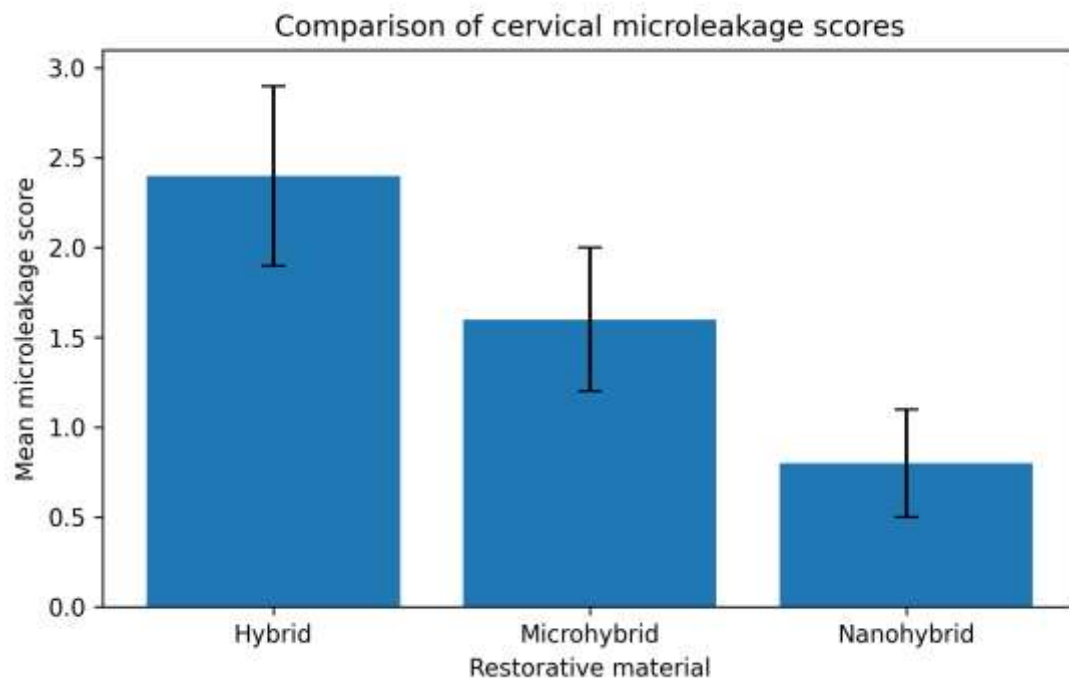
Cervical Microleakage Analysis

Microleakage assessment was carried out using dye penetration analysis under stereomicroscopy following thermocycling. The hybrid composite group demonstrated the highest degree of cervical microleakage with a mean score of 2.4 ± 0.5 . Most specimens in this group exhibited dye penetration extending beyond half of the gingival wall, and several samples demonstrated penetration approaching the axial wall.

The microhybrid composite group demonstrated moderate microleakage values with a mean score of 1.6 ± 0.4 . The nanohybrid composite group exhibited the lowest microleakage values with a mean score of 0.8 ± 0.3 . In the majority of specimens in the nanohybrid group, either no dye penetration or only minimal superficial penetration was observed.

Group	Composite type	Mean microleakage score
Group I	Hybrid composite	2.4 ± 0.5
Group II	Microhybrid composite	1.6 ± 0.4
Group III	Nanohybrid composite	0.8 ± 0.3

Table 2: Mean cervical microleakage scores among study groups.



Graph 2: Comparison of cervical microleakage scores among study groups.

Correlation Between Cuspal Deflection and Microleakage

A positive correlation was observed between cuspal deflection and cervical microleakage. Restorative materials demonstrating greater cuspal deformation also exhibited higher marginal leakage scores. This relationship suggests that polymerization contraction stress plays a critical role in compromising marginal integrity.

Discussion

Polymerization shrinkage remains one of the most significant drawbacks of resin-based restorative materials. Polymerization contraction stresses generated during curing can deform cusps and compromise marginal adaptation [2,6]. These stresses may further lead to postoperative sensitivity, enamel cracks, marginal staining, and secondary caries.

In the present study, hybrid composites demonstrated the highest cuspal deflection. This may be attributed to the presence of TEGDMA in the resin matrix, which increases polymerization shrinkage because of higher concentration of reactive carbon double bonds [9,10]. Similar findings were reported by Fleming et al. [9] and Lee and Park [10], who observed greater cuspal deformation with conventional hybrid composites compared with newer low-shrinkage materials.

Microhybrid composites demonstrated lower cuspal deflection than hybrid composites because of improved filler loading and optimized filler distribution [3]. The incorporation of colloidal silica fillers enhances the mechanical properties and reduces polymerization stress generation.

Nanohybrid composites showed the least cuspal deflection among all tested groups. This superior performance may be explained by the incorporation of nanosized filler particles and modified resin chemistry involving UDMA and Bis-EMA systems [13]. These materials exhibit lower polymerization shrinkage and improved stress distribution during curing.

The present study also demonstrated significantly reduced cervical microleakage in nanohybrid composite restorations. Reduced polymerization shrinkage stress may preserve adhesive integrity and minimize gap formation at the tooth-restoration interface [11,12]. Bagis et al. [12] similarly reported lower microleakage scores with newer restorative systems.

Incremental placement technique was employed in the present study to minimize polymerization contraction stress [6]. Although incremental placement reduced stress concentration, measurable cuspal deflection was still observed in all groups. Versluis et al. [6] reported that each increment contributes individually to stress generation, and therefore polymerization contraction cannot be completely eliminated.

Thermocycling was performed to simulate oral environmental conditions and assess long-term marginal adaptation. Gingival margins demonstrated greater dye penetration than enamel margins, likely because dentin bonding remains less predictable compared with enamel bonding [8].

Flowable liners and low-shrinkage restorative systems have been proposed to further reduce polymerization stress and improve marginal adaptation [11,14,15]. Studies by Moorthy et al. [14] and Karaman and Ozgunaltay [15] demonstrated that bulk-fill flowable composites and resin-modified glass ionomer liners may reduce cuspal deflection in posterior restorations.

Cuspal deflection observed in the present study indicates that cavity dimensions and remaining tooth structure significantly influence stress distribution during polymerization [4,5]. Larger MOD cavities with thinner remaining cusps tend to exhibit greater deformation.

The findings of the present study suggest that nanohybrid composites provide superior marginal integrity and reduced cuspal strain compared with hybrid and microhybrid composites. Their improved filler technology and modified resin matrix may contribute to enhanced clinical longevity and better restorative outcomes in posterior stress-bearing restorations.

Conclusion

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

All composite restorative materials exhibited cuspal deflection and cervical microleakage.

Hybrid composites demonstrated maximum cuspal deflection and dye penetration.

Nanohybrid composites showed significantly reduced cuspal deflection and cervical microleakage.

Modified resin chemistry and nanosized filler particles contributed to improved performance of nanohybrid composites.

Nanohybrid composites may provide superior clinical longevity and marginal integrity in posterior restorations.

Clinical Significance

Selection of restorative material plays a crucial role in the longevity of posterior composite restorations. Nanohybrid composites, because of their reduced polymerization shrinkage and improved marginal adaptation, may reduce postoperative complications and improve restoration durability in extensive posterior cavities.

Limitations

The study was conducted under in vitro conditions.

Oral environmental factors such as saliva, occlusal forces, and masticatory stresses were not fully reproduced.

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Long-term aging and fatigue behavior were not evaluated.

The study was limited to selected restorative materials and a defined sample size.

Future Scope

Long-term clinical studies should be conducted.

Evaluation under cyclic loading conditions may provide more clinical relevance.

Advanced imaging techniques such as micro-CT can be used for precise assessment of marginal gaps.

Comparison with newer bulk-fill and bioactive restorative materials may be performed.

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