Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI: 10.53555/h8c8zc82

COMPARATIVE ANALYSIS OF FRACTURE MODES IN DIRECT COMPOSITE VENEERS PREPARED WITH BEVEL AND INCISAL OVERLAP DESIGNS: AN IN VITRO MICROSCOPIC EVALUATION

Submission date: 7th August, 2025
Acceptance date: 25th September, 2025
Publication date: 24th October, 2025

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Abstract

Background: Preparation geometry may influence not only how much load a veneer withstands but how it fails information that matters for prognosis and repair.

Objective: To compare failure modes of direct nanohybrid composite veneers fabricated with bevel versus incisal-overlap preparations.
Materials and Methods: Eighty extracted maxillary central incisors were prepared and restored with a standardized adhesive protocol and nanohybrid composite, then thermocycle (300 cycles, 5–55 °C). Group A received a bevel design; Group B received an incisal-overlap design (n=40 each). Specimens were loaded to failure; fractured teeth and fragments were examined under a stereomicroscope (40×) and categorized as cohesive (in resin), adhesive (tooth–resin interface), or mixed. Failure-mode distributions were compared using chi-square tests (α=0.05).
Results: Failure patterns differed significantly by preparation design ($\chi^2(2)$ =19.2, p<0.001). Bevel preparations showed more cohesive failures (24/40, 60%) and fewer adhesive (4/40, 10%) and mixed failures (12/40, 30%). Incisal-overlap preparations showed more adhesive (16/40, 40%) and mixed failures (18/40, 45%), with cohesive failures least frequent (6/40, 15%).
Conclusions: Preparation design influences how direct composite veneers fail. Bevel designs are more likely to produce cohesive often more repairable failures, whereas incisal-overlap designs show greater interfacial (adhesive) and mixed failures. These findings support beveling when long-term maintenance and repairability are priorities; validation under cyclic loading and with varied adhesive systems is warranted.

Keywords: direct composite veneer; bevel; incisal overlap; failure mode; adhesive failure; cohesive failure; stereomicroscopy; chi-square.

Introduction

Traumatic fractures of maxillary incisors are a routine challenge in restorative practice and demand solutions that balance esthetics, function, and conservation of tooth structure (1). Adhesive dentistry has expanded the spectrum of conservative options from fragment reattachment to veneers allowing predictable reconstructions with minimal sacrifice of sound tissue (2). Among veneer strategies, ceramic laminates demonstrate excellent longevity, favorable wear behavior, and superior color stability, with survival rates approaching 99% in mid-term follow-up (3–7). Their performance, however, is modulated by factors beyond material selection alone, including tooth morphology and preparation geometry (3). Partial laminate approaches further limit tissue removal through additive designs (8).

Direct composite veneers offer a cost-effective, single-visit alternative that preserves enamel and enables easy repair (2). Yet, they exhibit greater wear and color instability over time, and long-term studies report fracture as a prominent reason for failure in anterior Class IV restorations (2,9). Preparation design is central to biomechanical behavior: bevels are intended to increase enamel bonding area and stress diffusion across a tapered margin, whereas incisal-overlap designs extend coverage to the palatal surface, potentially altering load transfer pathways and crack propagation patterns under functional or impact forces. Despite the clinical relevance of these mechanics, most comparative investigations in this domain emphasize fracture strength rather than the nature and distribution of fracture modes information that directly informs failure prognosis, reparability, and retreatment planning.

Nanohybrid composites, with their optimized filler technology, have improved polish retention and mechanical properties relative to prior resin systems, making them suitable for anterior veneers subjected to complex loading. However, whether a bevel or an incisal-overlap preparation better mitigates unfavorable fractures such as catastrophic substrate involvement versus repairable cohesive failures in the veneer remains insufficiently characterized in vitro. Clarifying how preparation geometry influences fracture mode can refine case selection, margin design, and patient-specific risk counseling.

This study therefore, aims to compare the fracture modes of direct nanohybrid composite veneers fabricated with bevel versus incisal-overlap preparations under controlled in-vitro conditions. By shifting the emphasis from “how much load until failure” to “how failure happens,” the work seeks clinically actionable insights that complement existing survival data on veneers and align with the contemporary mandate for minimally invasive, repair-friendly esthetic dentistry (1–9).

Materials and Methods

This quasi-experimental in-vitro study was conducted over 12 months in the Department of Conservative Dentistry and Endodontics, Bangladesh Medical University (BMU), with mechanical testing at BCSIR, Dhaka. Freshly extracted human maxillary central incisors were collected by consecutive sampling. Teeth were included only if intact, free of caries, cracks, restorations, developmental defects, open apices, prior endodontic treatment, or trauma; those not meeting these criteria were discarded. Specimens were cleaned ultrasonically, stored in water at room temperature with weekly refreshment, and then randomly allocated to two groups of equal size: bevel preparation and incisal-overlap preparation. The sample size per group was determined for comparing two independent means using

$$n = \frac{(u+v)^2\,(\sigma_1{}^2+\sigma_0{}^2)}{(\mu_1-\mu_0)^2}$$

With u=0.84, v=1.96, μ_1=385, μ_0=271, σ_1=225, and σ_0=100. The calculation yielded n=36.57, rounded to 40 per group (total N=80) based on prior data. Tooth preparations were performed with an air-turbine and round-ended tapered diamond (ISO 856018). For both designs, facial reduction was approximately 0.5–0.75 mm mid-facially, tapering to 0.3–0.5 mm near the gingival margin. In the bevel group, the incisal edge was reduced 1.5 mm, and a 1.0-mm facial bevel was prepared. In the incisal-overlap group, the incisal reduction was 1.5–2.0 mm with palatal extension to create an overlap.

All teeth were restored immediately, following the manufacturer's instructions. Enamel was etched for 30 s and dentin for 10 s with 37% phosphoric acid; a universal adhesive (CLEARFIL S Bond Universal, Kuraray Noritake) was applied, and veneers were built incrementally using nanohybrid composite (CLEARFIL AP-X Esthetic), each increment light-cured for 20 s with an LED unit. Finishing and polishing were completed with Bioclear burs and SHOFU Super-Snap systems. Specimens underwent 300 thermocycles between 5 °C and 55 °C (30-s dwell, 10-s transfer).

For fracture testing, roots were embedded in self-cure acrylic up to 2 mm below the CEJ and mounted in a universal testing machine at 45° using a custom jig. A compressive load was applied to the palatal incisal third at 1 mm/min until failure, and peak load (N) was recorded. Post-fracture, teeth and veneer fragments were examined under a stereomicroscope (40×) to classify adhesive, cohesive (in resin), or mixed failures. Fracture strength was compared between groups using Student's t-test, while fracture-mode distributions were analyzed with chi-square tests (α=0.05) in SPSS v26. Ethical approval was obtained from the BMU IRB, and de-identified data were stored securely.

Result

A total of 80 specimens were included and allocated equally to the two preparation groups. Group A (Bevel) comprised 40 specimens (50%), and Group B (Incisal Overlap) comprised 40 specimens (50%), ensuring balanced group sizes for comparison.

Table 1: Distribution of Patients in both groups by percentage (n=80)

Group	*Frequency*	*Percentage (%)*
A (Bevel)	40	50
B (Incisal Overlap)	40	50
Total	**80**	**100**

The Radar plot shows across the two preparation designs, mixed failures were the most frequent in both groups, followed by cohesive or adhesive failures depending on preparation. In the bevel group (Group A), mixed failures (n=36) predominated, with fewer cohesive (n=24) and the fewest adhesive failures (n=8). In contrast, the incisal-overlap group (Group B) showed a marked increase in adhesive failures (n=32) alongside the highest mixed failures (n=54), while cohesive failures were least common (n=6). Taken together, bevel preparations tended to fail within the material (cohesive/mixed), whereas incisal-overlap preparations showed a greater propensity for debonding-related events (adhesive/mixed).

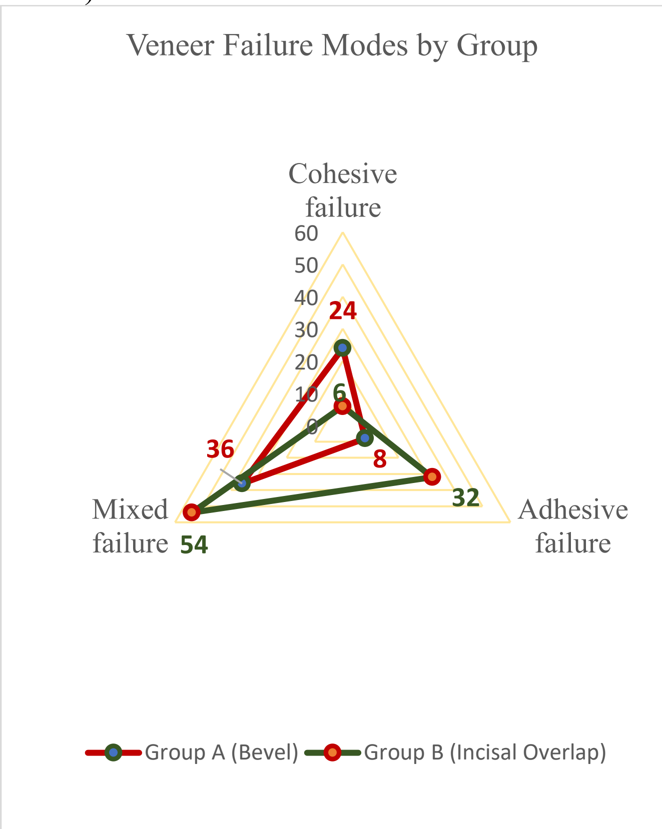

Figure 1: Frequency distribution of veneer failure modes by preparation design

Across 80 specimens (n=40 per group), failure patterns differed clearly by preparation design. In the bevel group, cohesive failures predominated (24/40, 60%), with mixed (12/40, 30%) and adhesive (4/40, 10%) less frequent. In the incisal-overlap group, mixed (18/40, 45%) and adhesive failures (16/40, 40%) were most common, while cohesive failures were least frequent (6/40, 15%). A chi-square test of independence showed a significant association between preparation design and failure mode,
χ^2 (2) =19.2, $p<0.001$.

*Table 2: **Association of mode of fracture between two groups (n=80)***

Mode of fracture	Group A (n=40)	Group B (n=40)	p-value
Cohesive failure	24(60.0%)	6(15.0%)	<0.001
Adhesive failure	4 (10.0%)	16(40.0%)	
Mixed	12(30.0%)	18(45.0%)	
Total	**40(100.0%)**	**40(100.0%)**	

Data were expressed as frequency and percentage, p value obtained by Chi-square test, p<0.05 was considered as a level of significant

There was a significant association between preparation design and failure mode ($\chi^2(2)=19.2$, $p<0.001$). Cohesive failure was markedly more common in the bevel group (Group A: 24/40, 60%) than in the incisal-overlap group (Group B: 6/40, 15%). Conversely, adhesive failure occurred far more frequently in Group B (16/40, 40%) than in Group A (4/40, 10%), and Group B also showed a higher proportion of mixed failures (18/40, 45% vs 12/40, 30%). Collectively, these differences indicate that bevel preparations predominantly exhibited cohesive failures, whereas incisal-overlap preparations were characterized by greater frequencies of adhesive and mixed failures, confirming a statistically significant divergence in failure-mode distributions between the groups.

Discussion

This in-vitro analysis focused on how preparation design influences failure mode of direct nanohybrid composite veneers, not their load-to-failure values. The distribution of failures differed significantly between groups: bevel preparations showed mainly cohesive failures, while incisal-overlap preparations exhibited more adhesive and mixed failures. In practical terms, beveling tended to keep the bond intact and localize fracture within the restorative material, whereas incisal overlap more often compromised the tooth–resin interface. The predominance of cohesive failures with beveling aligns with adhesive mechanics. A bevel exposes more prismatic enamel, increases surface energy, and enlarges the enamel bonding area, improving micromechanical retention and stress diffusion across the margin. Higher interfacial integrity is known to shift failures from the interface to the material itself i.e., from adhesive to cohesive modes (10–13). Reports have shown that bevel designs raise shear bond strength and enhance marginal integrity in both primary and permanent teeth, thereby increasing the likelihood of cohesive or mixed rather than purely adhesive failures (12, 13). Our mode pattern is consistent with that rationale.

By contrast, the incisal-overlap design showed a greater share of adhesive and mixed failures. Several mechanisms may explain this tendency. Extending the finish line palatally changes the direction and lever arm of applied forces at the incisal third; under oblique loading, tensile stresses may concentrate at the adhesive interface rather than dissipate along a beveled enamel margin. Finite-element and experimental observations indicate that when enamel beveling is absent or minimal at critical load paths, the interface experiences higher tensile stress and is more prone to debonding (14–16). The larger bonded area in an overlap design does not automatically translate into a more durable interface if stress trajectories are unfavorable or if film thickness and insertion path complicate seating and curing in deep palatal extensions—factors that can leave parts of the interface vulnerable to hydrothermal and mechanical challenges (14–16).

Clinically, these patterns matter because failure mode dictates reparability. Cohesive failures within the veneer are often amenable to additive repair or partial replacement, while adhesive failures imply interfacial compromise and may require full rebonding with renewed isolation and surface pretreatment. From a minimally invasive perspective, a preparation that favors cohesive or mixed failures without encouraging catastrophic substrate involvement is preferable when esthetic maintenance and repairability are priorities.

Two points temper generalization. First, this was an in-vitro study with controlled thermocycling and monotonic loading; fatigue, parafunction, contamination, operator variability, and occlusal dynamics in vivo may shift mode distributions. Second, only one adhesive/composite system and standardized reductions were used; alternative materials or bonding protocols (e.g., selective-enamel etch vs universal strategies) could alter interfacial performance and thus failure mode.

Within these limits, the data support a pragmatic takeaway: bevel preparations are more likely to fail cohesively (repair-friendly), whereas incisal-overlap preparations carry a higher risk of adhesive and mixed failures. For cases prioritizing long-term maintenance and straightforward repair, emphasizing enamel bevels, meticulous isolation, and controlled film thickness at margins remains advisable. Future work should couple failure-mode mapping with cyclic fatigue and 3D stress analyses to refine preparation guidance across different adhesives and composites.

Conclusion

Preparation design significantly influenced the **failure mode** of direct nanohybrid composite veneers. Bevel preparations predominantly exhibited **cohesive failures** (24/40, 60%), whereas incisal-overlap preparations showed higher frequencies of **adhesive** (16/40, 40%) and **mixed** failures (18/40, 45%); the association between preparation design and failure mode was statistically significant ($p<0.001$). Taken together, these findings indicate that beveling is more likely to preserve interfacial integrity and channel failure within the restorative material, supporting a repair-friendly, minimally invasive approach to anterior veneer rehabilitation.
From a clinical standpoint, selecting a bevel design may improve maintainability and simplify future interventions, while cases planned with an incisal-overlap design warrant heightened attention to interfacial management (isolation, enamel preservation, adhesive protocol, curing access) to mitigate debonding-related outcomes. Further work incorporating cyclic fatigue, varied adhesive systems, and alternative composites will help generalize and refine these preparation-specific recommendations.

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