

# Biomechanical Behavior of MOD Composite Restorations Reinforced with InFibra versus Ribbond Polyethylene Fibers: An In Vitro Evaluation

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## Article

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# Abstract

## Background

Recent advancements in restorative materials, particularly fiber-reinforced composites, have enhanced the reinforcement of weakened teeth and improved their ability to withstand masticatory forces. The aim of this in vitro study was to evaluate the biomechanical performance of InFibra and Ribbond in MOD cavity restorations by assessing fracture resistance under simulated masticatory loading and analyzing failure patterns.

## Methods and Material:

A total of 90 extracted, caries-free human mandibular molars were utilized. Standardized mesio-occluso-distal (MOD) cavities were prepared. The teeth were randomly allocated into three groups (n = 30). Group 1 (control, restored with a bulk-fill composite Jen-Radiance Molar), Group 2 (Restored with INFIBRA polyethylene fibers followed by same bulk-fill composite), and Group 3 (Restored with RIBBOND polyethylene fibers followed by same bulk-fill composite). Specimens were thermocycled for a total of 1000 cycles for a 20s. Fracture resistance test was performed. Fractures patterns were examined under stereomicroscope. Data was analyzed using one-way ANOVA test followed by Tukey's post hoc test to detect the significance difference between groups ( $p = 0.05$ ).

## Results

Statistically significant differences in fracture resistance were observed among the three groups ( $p < 0.001$ ), with a moderate effect size. The Control group exhibited predominantly unfavorable failures (73.33%). In contrast, both the InFibra and Ribbond groups showed significantly higher percentages of favorable failures (80.00% each) compared to the Control group ( $p < 0.001$  for both). Adhesive failures occurred significantly more frequently in the InFibra and Ribbond (60.00%) groups. Cohesive restoration & substrate failures were significantly more common in the Control group (33.33%).

## Conclusions

polyethylene fiber reinforcement did not improve the fracture resistance of mesio-occluso-distal (MOD) composite restorations; however, both systems significantly promoted more favorable, repairable failure patterns.

## Introduction

The loss of dental tissue fundamentally alters biomechanical properties, compromising structural stiffness and load distribution, which adversely affects both the tooth and surrounding dentition.

Restoring extensively damaged posterior teeth with large MOD cavities remains challenging due to reduced cuspal support and internal structure loss, increasing stress concentrations and fracture susceptibility under masticatory forces.<sup>1</sup> MOD class II cavities, involving mesial, occlusal, and distal surfaces, are especially destructive reducing fracture resistance by 54% compared to sound teeth. The loss of marginal ridges, key for stability, amplifies stress concentrations and horizontal forces that easily fracture remaining cavity walls, leading to markedly decreased fracture resistance.<sup>2</sup>

Composite restorations for posterior teeth have insufficient fracture resistance, as modern resins lack adequate toughness despite high rigidity. Although resin bonding theoretically acts as an internal splint to restore lost tooth strength, evidence shows this strengthening effect is unreliable in large cavities. Studies indicate that conventional composites in extensive posterior cavities are associated with increased risks of tooth fracture, restoration fracture, secondary caries, and marginal defects.<sup>3</sup> Polymerization shrinkage remains a major limitation, creating interfacial stresses that compromise marginal integrity and predispose to microleakage. Consequently, direct composite restorations alone do not reliably restore fracture resistance in structurally compromised posterior teeth.<sup>4</sup>

The biomimetic approach studies natural tooth structure to design materials and techniques that restore teeth with minimal invasiveness while replicating their mechanical properties. A long-standing concept involves using fibers of varying sizes and orientations beneath resin composite to enhance hardness and fracture strength.<sup>5</sup> Biomimetic dentistry focuses on restoring a tooth's original biomechanical integrity by matching the elastic modulus and surface hardness of natural tissues. This ensures even stress distribution, reduces fracture risk, and preserves dental tissue integrity. Key factors include matching thermal expansion and tensile strength to natural teeth for optimal performance under functional loads. Fiber-reinforced composites aligned with these principles offer a promising strategy for structurally compromised posterior teeth.<sup>6</sup>

Fiber-reinforced composites (FRCs) combine a polymer matrix with reinforcing fibers that create pathways to withstand occlusal stress, with fibers placed in various orientation patterns. Studies show FRCs increase fracture strength and reduce microleakage by minimizing polymerization shrinkage, while distributing occlusal loads more evenly to prevent premature failure. This innovation offers superior durability in high-stress posterior regions where traditional composites fail due to polymerization shrinkage, secondary caries, or marginal breakdown.<sup>7</sup> Among these advanced polyethylene fibers, Ribbond and InFibra have gained significant attention in dental applications for their ability to reinforce composite restorations, improving durability and performance.<sup>8</sup>

Ribbond, a pre-impregnated, plasma-treated polyethylene fiber, acts as a "crack stopper" and improves load distribution, increasing restoration durability and promoting favorable, non-catastrophic fracture patterns.<sup>4,6</sup> InFibra, a next-generation ultra-high-molecular-weight polyethylene fiber, features enhanced surface characteristics achieving flexural strengths up to 296 MPa after plasma treatment, closely

mimicking natural dentin.<sup>9</sup> Evidence shows both fibers distribute occlusal loads evenly, reducing polymerization shrinkage stress and microleakage in large MOD cavities.<sup>10</sup>

Recent studies have demonstrated that fiber reinforcement can significantly influence the fracture resistance, bond strength, and failure patterns of composite restorations.<sup>10,11</sup> However, comparative evaluations between InFibra and Ribbond in MOD cavity restorations particularly in terms of fracture resistance and mode of failure remain limited. Therefore, this study was designed to evaluate the reinforcing effect of polyethylene fibers (Ribbond versus Infibra) in the fracture resistance and mode of failure in mesio-occluso-distal (MOD) cavities class II restorations. The null hypothesis of the current study was that there was no significant difference between the fracture resistance and the mode of failure of teeth restored with bulk fill composites reinforced with polyethylene fibers and restored with bulk fill composite only.

## Methods

The present study was approved by Ethics Committee of Egyptian Russian University (approval no FD-ERU-REC 30) in compliance with the 1964 Helsinki Statement. All extracted teeth used in this study were collected from the Department of Oral and Maxillofacial Surgery after obtaining written informed consent from the patients.

## Sample Size Calculation:

The required sample size was determined using G\*Power version 3.1.9.7 software (G\* power; Heinrich Heine University, Düsseldorf, Germany), based on the results of a comprehensive pilot study. Assuming a medium effect size (Cohen's  $f^2 = 0.25$ ),  $\alpha = 0.05$ , and power = 0.80 for a one-way ANOVA (three groups), the initial estimate was 22 teeth per group ( $N = 66$ ). To account for potential specimen attrition and ensure a clinically robust estimate, the sample size was increased to 30 teeth per group, yielding a final total of 90 extracted human molars ( $n = 30$  per group;  $N = 90$ ). This sample size provides adequate power to detect significant differences in fracture resistance among the tested fiber-reinforced composite systems and allows for descriptive analysis of failure pattern.

## Sample Preparation:

In the present study, a total number of ninety human intact mandibular molar teeth of similar sizes and morphologies were selected. Teeth with intact crowns, mature apices, and no evidence of cracks, cavitation, restorations, abrasions, or structural anomalies were included. Teeth with open apices, hypoplastic defects, or previous restorations were excluded to ensure uniformity. A digital caliper was used to measure teeth buccolingually and mesiodistally at the cemento-enamel junction (CEJ); a variance of no more than 0.5 mm was permitted. An ultrasonic scaler (Guilin, China: Woodpecker) was

used to remove calculus and debris. Then, they were disinfected in a 0.1% thymol solution stored in distilled water at room temperature until use to prevent dehydration.<sup>12</sup>

Each tooth was mounted vertically in an auto-polymerizing acrylic resin block (Acrostone, Egypt) with the long axis perpendicular to the base. The root surface was coated with a uniform 0.5 mm layer of light-body vinyl polysiloxane (VPS) impression material (Zhermack Elit, Germany) to simulate the periodontal ligament. This layer allowed controlled tooth mobility and stress distribution during mechanical loading.<sup>13</sup>

## **Cavity Standardization:**

Standardized mesio-occluso-distal (MOD) cavities were prepared using a high-speed air-motor handpiece (NSK/Nakanishi Inc., Tokyo, Japan) under copious water cooling. A No. 245 tungsten carbide straight fissure bur (SS White Dental, Lakewood, NJ, USA) was used for cavity preparation. Each bur was replaced after every five preparations to maintain cutting efficiency and standardization. The cavity dimensions were standardized as follows: occlusal depth of 4 mm from the central fissure, buccolingual isthmus width of 4 mm, and axial pulpal depth of 2 mm. All cavity walls were prepared parallel to each other with a 90° cavosurface margin and rounded internal line angles. Following preparation, all cavities were finished using a yellow-coded finishing bur (Komet Dental, Lemgo, Germany or MANI, Tochigi, Japan). Cavity dimensions were verified using a digital Vernier caliper (Mitutoyo Corporation, Kawasaki, Japan); specimens with deviations exceeding  $\pm 0.1$  mm were excluded and replaced.

## **Grouping of teeth:**

The teeth were allocated randomly into three groups of 30 specimens each, based on the restorative protocol.

Group 1 (control): Restored with a bulk-fill base (Jen-Radiance Molar, JenDental, Ukraine) followed by an enamel layer of micro-hybrid composite (Jen Radiance Universal, JenDental Ukraine).

Group 2: Restored with INFIBRA polyethylene fibers (Bioloren Srl, Saronno, Italy) adapted to the cavity base, followed by the same bulk-fill base and enamel layer.

Group 3: Restored with RIBBOND polyethylene fibers (Ribbond Inc., Seattle, WA, USA) at the cavity base, followed by the same bulk-fill base and enamel layer. The materials and product details were presented in Table 1.

Table 1  
Materials used in this study

| Material                            | Manufacture                   | Composition                                                                                               | LOT Number                    |
|-------------------------------------|-------------------------------|-----------------------------------------------------------------------------------------------------------|-------------------------------|
| <b>Jen-Radiance Molar</b>           | JenDental, Ukraine            | High-density filler (82% wt), submicron hybrid, Bis-GMA based                                             | 291600                        |
| <b>Jen-Radiance Universal</b>       | JenDental, Ukraine            | Micro-hybrid composite, 79% wt filler, Bis-GMA based                                                      | 291529                        |
| <b>INFIBRA™ Polyethylene Fibers</b> | Bioloren Srl, Saronno, Italy  | Ultra-high molecular weight polyethylene (UHMWPE), bidirectional                                          | 21/04                         |
| <b>RIBBOND™ Polyethylene Fibers</b> | Ribbon Inc., Seattle, WA, USA | Pre-impregnated, silanized, plasma-treated, Ultra-high molecular weight polyethylene (UHMWPE), leno-woven | +D758T0/\$\$740/16D20250120/N |
| <b>Ceramage Modeling Liquid</b>     | Shofou Inc., Japan            | UDMA, Trimethylolpropane trimethacrylate<br><br>(Unfilled Resin).                                         | 112425                        |
| <b>Phospho-Jen AS</b>               | JenDental, Ukraine            | 37% Orthophosphoric acid and Cetrimonium Bromide.                                                         | 291673                        |
| <b>ALL-BOND UNIVERSAL</b>           | Bisco Inc., USA               | 10-MDP, BPDM, and Bis-GMA resins in an ethanol/water solvent system, featuring a mild pH (> 3.2)          | 240013035                     |

## Restorative procedure:

### Adhesive Protocol (Selective Enamel Etching)

Enamel margins were etched with 37% phosphoric acid gel (Ultra-Etch, Ultradent, USA) for 15 seconds, rinsed with water spray for 10 seconds, and gently air-dried, leaving the dentin moist. No phosphoric acid was applied to the dentin. ALL-BOND UNIVERSAL (Bisco Inc., USA) was then applied to the entire cavity in self-etch mode, scrubbed with a micro-brush for 15 seconds, air-thinned for 5 seconds, and light-cured for 10 seconds using an LED curing unit (3M Elipar Deep Cure-S LED Curing Light, 3M, USA) at an intensity of 1200 mW/cm<sup>2</sup>. Light intensity output was verified every 10 specimens using a digital readout light meter. A Tofflemire retainer with a circumferential matrix band was adapted and applied around the tooth prior to composite placement.

### Fiber Placement (Groups 2 and 3)

The polyethylene fiber ribbons (INFIBRA and RIBBOND) were both cut using the specialized stainless-steel scissors designed for RIBBOND (Ribbond Inc., Seattle, WA, USA). These scissors were selected because standard surgical scissors cannot cleanly cut ultra-high molecular weight polyethylene (UHMWPE) fibers without leaving stray uncut filaments, which could compromise the adaptation of the reinforcement or create voids. Using the same cutting instrument for both groups ensured standardization of the fiber-end morphology.

- **Group 2 (INFIBRA):** INFIBRA fibers (Bioloren Srl, Saronno, Italy; 4 mm width) were cut to size to adapt to the pulpal floor and axial walls of the MOD cavity. The fibers were wetted with Ceramage Modeling Liquid (Shofu Inc., Japan) prior to placement. The wetted fibers were adapted to the cavity base using a plastic instrument and light-cured for 20 seconds
- **Group 3 (RIBBOND):** RIBBOND-THM fibers (Ribbond Inc., Seattle, WA, USA; 4 mm width, 0.18 mm thickness) were cut into approximately 3 mm long segments using the manufacturer-specified specialized scissors to prevent stray uncut fibers. The fiber segments were wetted with Ceramage Modeling Liquid (Shofu Inc., Japan), adapted to the pulpal floor and axial walls of the MOD cavity, and positioned to be embedded within a 1 mm thick layer of the overlying composite restoration. Following placement, the fibers were light-cured for 20 seconds.

## Composite Restoration

After fiber stabilization (or directly after the adhesive protocol for Group 1), the same restorative protocol was followed for all groups:

1. **Bulk Fill Base Layer:** Jen-Radiance Molar (JenDental, Ukraine) was placed into the cavity in a single increment up to 5 mm thickness. The material was gently adapted to the cavity walls using a flat-end applicator (LM Arte Kit, LM Instruments, Finland). The bulk fill layer was light-cured for 40 seconds.
2. **Enamel Layer:** Jen-Radiance Universal (JenDental, Ukraine) was applied as the final 2 mm occlusal layer. The enamel layer was sculpted to reproduce the anatomical contour and occlusal morphology using composite instruments. The layer was light-cured for 40 seconds from occlusal, buccal, and lingual directions to ensure complete polymerization.

## Finishing and Polishing

After removal of the matrix band and Tofflemire retainer, gross excess was removed using a yellow-coded diamond finishing stone (SS White Burs, Inc., Lakewood, NJ, USA). Interproximal contacts were refined with finishing strips. Polishing was performed using a composite polishing kit (Compo Master, Shofu Inc., Japan) following the manufacturer's instructions.

## Storage and Aging:

After the restorations were placed, all the teeth were stored in an incubator at 37 °C and 100% humidity for 24 h prior to thermocycling aging. All teeth were removed from the acrylic blocks before thermocycling and then were thermocycled in a water bath at 5°C followed by 55° C for a total of 1000 cycles for a 20s dwell time each and an intermediary 5s resting time (SD Mechatronic thermocycler, Germany).<sup>14</sup>

## Fracture Resistance Testing

A Universal Testing Machine (Model 3345; Instron Industrial Products, Norwood, MA, USA) equipped with a 5 kN load cell was used to apply an increasing compressive load until fracture. Each specimen remained embedded in its acrylic resin block with the simulated periodontal ligament (0.5 mm VPS layer) intact. The acrylic block was firmly seated in the lower compartment of the testing machine using tightening screws to prevent any movement during loading. In the upper compartment, a 4 mm diameter stainless steel spherical attachment was mounted.<sup>15</sup> To simulate the functional oblique forces commonly experienced by posterior teeth during mastication, the load was applied at a 45° angle to the long axis of the specimen at a crosshead speed of 1 mm/min. This was achieved by tilting the specimen holder at 45° relative to the vertical axis of the testing machine.

The point of loading application was standardized to contact the buccal incline of the lingual cusp (for mandibular molars), approximately 2 mm from the occlusal surface. This placement was selected to concentrate shear and tensile stresses at the tooth-restoration interface, simulate functional cusp loading, and prevent specimen tipping during testing.

The maximum force at failure was recorded in Newtons (N). Fracture was identified visually

(Observation of crack propagation) and audibly (audible sound of fracture), and confirmed by a quick drop in the load deflection curve recorded using computer software (Blue Hill Instron).<sup>10</sup>

## Failure Mode Analysis

Following fracture testing, all specimens were examined under a stereomicroscope (Nikon SMZ800, Tokyo, Japan) at 20× magnification. Failure modes were classified according to the criteria established in previous studies<sup>16, 17</sup> as follows: adhesive, cohesive substrate, cohesive restoration, cohesive substrate and restoration, and mixed (adhesive and cohesive), as described in Table 2. Fracture types were also classified into two categories based on the fracture location: favorable (up to 1 mm below the CEJ) and unfavorable (more than 1 mm below the CEJ). Two evaluators conducted the fracture pattern analysis under magnification.

Table 2  
Distribution of failure modes among the three experimental groups according to the five-type classification system.

| Failure mode                              | Description                                                                                                  |
|-------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| <b>Adhesive</b>                           | Fracture occurring at the adhesive interface between the restorative material and the tooth structure        |
| <b>Cohesive substrate</b>                 | Fracture confined within the tooth substrate (enamel or dentin), not involving the restorative material      |
| <b>Cohesive restoration</b>               | Fracture confined within the restorative material, not involving the tooth structure                         |
| <b>Cohesive substrate and restoration</b> | Combined fracture involving both the tooth substrate and the restorative material simultaneously             |
| <b>Mixed (Adhesive and cohesive)</b>      | Fracture showing both adhesive failure at the interface and cohesive failure within the restoration or tooth |

## Statistical analysis:

Fracture resistance data were presented as means and standard deviation (SD) values. The peak force values for fracture in all specimens were assessed for normality using the Shapiro–Wilk test, and homogeneity of variance was examined using Levene’s test, with no substantial deviations. They were compared using a one-way ANOVA test followed by Tukey’s post hoc test. Failure modes were presented as frequencies and percentages. They were compared using the Chi-squared test with p-values derived using Monte Carlo simulations. Pairwise comparisons were performed using multiple z-tests, with adjustment for multiple comparisons using Holm’s method. Effect sizes were interpreted based on Cohen, J. (1988). The significance level was set at  $p < 0.05$  for all tests. Statistical analysis was performed with R statistical analysis software version 4.5.2 for Windows (R Core Team, 2025)

## Results

### Fracture Resistance:

The intergroup comparison of fracture resistance is presented in Table 3 and illustrated in Fig. 1. The highest mean fracture resistance was observed in the Control group ( $1733.74 \pm 533.17$  N), followed by the InFibra ( $1350.12 \pm 367.71$  N) and Ribbond ( $1232.78 \pm 258.60$  N) groups. A one-way ANOVA revealed a statistically significant difference among the three groups ( $p < 0.001$ ), with a moderate effect size (partial eta squared = 0.23; 95% CI: 0.12 to 0.36).

### Mode of Failure:

Failure mode distributions were analyzed in two complementary ways: first by specific failure types (Table 4, Fig. 2), and second by classifying failures as favorable or unfavorable (Table 3, Fig. 3).

Table 3  
Intergroup comparison of fracture resistance.

| Fracture resistance (Mean $\pm$ SD) (N) |                                   |                                   | <i>p</i> -value    | PES (95% CI)               |
|-----------------------------------------|-----------------------------------|-----------------------------------|--------------------|----------------------------|
| Control                                 | InFibra                           | Ribbond                           |                    |                            |
| 1733.74 $\pm$ 533.18 <sup>A</sup>       | 1350.12 $\pm$ 367.71 <sup>B</sup> | 1232.78 $\pm$ 258.60 <sup>B</sup> | <b>&lt; 0.001*</b> | <b>0.23 (0.12 to 0.36)</b> |

PES: Partial Eta Squared; CI: Confidence interval; Values with different superscripts are significantly different; \* significant ( $p < 0.05$ ).

Table 4  
Intergroup comparison of failure modes distribution (A).

| Mode of failure                             | n (%)                    |                          |                          | <i>p</i> -value    | Cohen's W (95% CI)         |
|---------------------------------------------|--------------------------|--------------------------|--------------------------|--------------------|----------------------------|
|                                             | Control                  | InFibra                  | Ribbond                  |                    |                            |
| <b>Adhesive</b>                             | 3 (10.00%) <sup>A</sup>  | 18 (60.00%) <sup>B</sup> | 18 (60.00%) <sup>B</sup> | <b>&lt; 0.001*</b> | <b>0.69 (0.41 to 0.84)</b> |
| <b>Cohesive substrate</b>                   | 1 (3.33%) <sup>A</sup>   | 1 (3.33%) <sup>A</sup>   | 0 (0.00%) <sup>A</sup>   |                    |                            |
| <b>Cohesive restoration</b>                 | 5 (16.67%) <sup>A</sup>  | 0 (0.00%) <sup>A</sup>   | 0 (0.00%) <sup>A</sup>   |                    |                            |
| <b>Cohesive restoration &amp; substrate</b> | 10 (33.33%) <sup>A</sup> | 0 (0.00%) <sup>B</sup>   | 0 (0.00%) <sup>B</sup>   |                    |                            |
| <b>Mixed</b>                                | 11 (36.67%) <sup>A</sup> | 11 (36.67%) <sup>A</sup> | 12 (40.00%) <sup>A</sup> |                    |                            |

CI: Confidence interval; Values with different superscripts within the same horizontal row are significantly different; \* significant ( $p < 0.05$ ).

## Failure Mode Distribution (A)

The distribution of failure modes across the three groups is summarized in Table 4. A chi-square test with Monte Carlo simulation indicated a statistically significant association between group type and failure mode distribution ( $p < 0.001$ ), with a large effect size (Cohen's  $W = 0.69$ ; 95% CI: 0.41 to 0.84). Pairwise comparisons with Holm's adjustment revealed those Adhesive failures occurred significantly more frequently in the InFibra and Ribbond (60.00%) groups compared to the Control group (10.00%) ( $p < 0.001$  for both). Cohesive restoration & substrate failures were significantly more common in the Control group (33.33%) than in either the InFibra or Ribbond (0.00%) groups ( $p < 0.001$  for both). No significant differences were observed among groups for cohesive substrate, cohesive restoration, or mixed failure modes ( $p > 0.05$  for all).

## Favorable and unfavorable Failure Classification (B)

As shown in Table 5, the distribution into favorable and unfavorable failures also yielded a statistically significant difference among groups ( $p < 0.001$ ), with a large effect size (Cohen's  $W = 0.52$ ; 95% CI: 0.30 to 0.72). The Control group exhibited predominantly unfavorable failures (73.33%), with only 26.67% favorable failures. In contrast, both the InFibra and Ribbond groups showed significantly higher percentages of favorable failures (80.00% each) compared to the Control group ( $p < 0.001$  for both). No significant difference was found between the InFibra and Ribbond groups regarding favorable/unfavorable failure distribution.

The modes of failure observed in all experimental groups were classified as adhesive, cohesive, or mixed, and further categorized as favorable or unfavorable. Representative illustrations of each failure pattern are presented in Fig. 4.

Table 5  
Intergroup comparison of Classification (B).

| Mode of failure    | n (%)                    |                          |                          | <i>p</i> -value    | Cohen's W (95% CI)         |
|--------------------|--------------------------|--------------------------|--------------------------|--------------------|----------------------------|
|                    | Control                  | InFibra                  | Ribbond                  |                    |                            |
| <b>Favorable</b>   | 8 (26.67%) <sup>A</sup>  | 24 (80.00%) <sup>B</sup> | 24 (80.00%) <sup>B</sup> | <b>&lt; 0.001*</b> | <b>0.52 (0.30 to 0.72)</b> |
| <b>Unfavorable</b> | 22 (73.33%) <sup>A</sup> | 6 (20.00%) <sup>B</sup>  | 6 (20.00%) <sup>B</sup>  |                    |                            |

CI: Confidence interval; Values with different superscripts within the same horizontal row are significantly different; \* significant ( $p < 0.05$ ).

## Discussion

The present in vitro study investigated the influence of two polyethylene fiber reinforcement systems, InFibra and Ribbond, on the fracture resistance and failure patterns of molars restored with standardized Class II MOD cavities under simulated oral conditions. The findings demonstrated a statistically significant difference in fracture resistance among the experimental groups ( $p < 0.001$ ), with a moderate effect size (partial  $\eta^2 = 0.23$ ), indicating that fiber reinforcement exerted a measurable, although not substantial effect on the resistance of restored teeth to fracture.

Unexpectedly, the control group restored with bulk-fill composite alone exhibited the highest mean fracture resistance values, followed by the InFibra and Ribbond groups, with no statistically significant difference observed between the two fiber-reinforced systems. These results suggest that the incorporation of polyethylene fibers did not enhance the ultimate load-bearing capacity of the restorations. The comparable performance of InFibra and Ribbond may be attributed to their similar reinforcing mechanisms and stress-distributing properties within the composite restoration.

In contrast, analysis of the failure mode revealed a highly significant difference among the groups ( $p < 0.001$ ), with a large effect size (Cohen's  $W = 0.52$ ; 95% CI: 0.30–0.72). The control group predominantly

exhibited unfavorable fractures (73.33%), whereas both fiber-reinforced groups demonstrated a markedly higher incidence of favorable failures (80.00% for both InFibra and Ribbond). Adhesive failures were significantly more frequent in the fiber-reinforced groups, whereas cohesive restoration–substrate fractures were observed exclusively in the control group. These findings indicate that, although polyethylene fiber reinforcement did not increase fracture resistance, it significantly altered the fracture behavior of restored teeth, resulting in more repairable and clinically favorable failure patterns.

Accordingly, the null hypothesis was rejected with respect to fracture resistance. The observed shift toward favorable fracture modes supports the concept that polyethylene fibers act primarily by modifying stress distribution within the restoration-tooth complex and by arresting or deflecting crack propagation. Consequently, fiber reinforcement appears to improve the fracture behavior and clinical reparability of restored teeth rather than increasing their intrinsic resistance to fracture under compressive loading.

The finding that polyethylene fiber reinforcement did not enhance load-bearing capacity is consistent with the findings of Mohammadipour et al., who reported no significant differences in fracture resistance between conventional composite restorations and Ribbond-reinforced groups in vital teeth with MOD cavities. The authors attributed this to the presence of an intact pulp–dentin complex and sufficient remaining tooth structure, suggesting that adhesive restorations alone may provide adequate reinforcement without the need for fiber incorporation <sup>4</sup>. Similarly, Cobankara et al. found no significant improvement in fracture resistance with the use of polyethylene fibers in endodontically treated teeth, indicating that the reinforcing effect of fibers is not consistently observed even in structurally compromised conditions <sup>18</sup>.

Reis et al. critically evaluated biomimetic restorative protocols and concluded that the placement of fiber inserts within composite restorations does not provide proven mechanical advantages over contemporary adhesive techniques. They emphasized that most available evidence supporting fiber reinforcement is derived from in vitro studies, which occupy a lower level in the evidence hierarchy, and highlighted the lack of randomized clinical trials demonstrating clear clinical superiority. These conclusions support the present findings and reinforce the fact that fiber reinforcement may not significantly improve the ultimate fracture resistance of restorations. <sup>19</sup>

The lack of reinforcement observed in the present study may be explained by several factors. Fiber incorporation introduces additional interfaces within the restorative complex, and any inadequacy in fiber impregnation, adaptation, or bonding may result in stress concentration sites rather than reinforcement. This explanation is further supported by a systematic review and meta-analysis by Alvarado-Orozco et al. who reported that polyethylene fibers were associated with increased gap formation, potentially compromising the integrity of the restoration. Furthermore, the effectiveness of fiber reinforcement is highly dependent on fiber orientation, position, and handling technique, which may influence stress distribution under loading conditions and limit their reinforcing potential. <sup>20</sup>

This apparent discrepancy between fracture resistance and failure mode is well documented in the literature. Alvarado-Orozco et al., reported that fiber insertion did not significantly increase fracture strength but significantly improved fracture patterns by increasing the incidence of favorable failures.<sup>20</sup> In agreement, multiple systematic reviews and meta-analyses have demonstrated that fiber reinforcement, particularly polyethylene fibers and short fibers reinforced composites, significantly reduces catastrophic fractures and increases the likelihood of repairable failures.

The underlying mechanism for this behavior is related to the biomechanical properties of fibers within the composite matrix. Fiber reinforcement acts primarily by enhancing fracture toughness rather than ultimate strength. Fibers function as a stress distributing and crack-arresting network, absorbing and dissipating energy under load and preventing crack propagation into the tooth structure. Polyethylene fibers, such as Ribbond, provide a stress-absorbing layer and may contribute to cusp splinting, whereas short fibers create a three-dimensional crack-stopping effect through random orientation and fiber pull-out mechanisms. As a result, stresses are redirected toward the adhesive interface, leading to more favorable and repairable failure patterns rather than catastrophic structural fracture<sup>8</sup>.

Although a statistically significant difference in fracture resistance was observed among the experimental groups, the clinical relevance of this difference should be interpreted with caution. The mean fracture resistance values recorded for all tested restorations exceeded the maximum bite forces typically generated in the posterior region, which have been reported to reach approximately 880 N in normal individuals and up to 1120 N in individuals exhibiting parafunctional habits. Therefore, despite the lower fracture resistance values exhibited by the fiber-reinforced groups compared with the bulk-fill composite group, all restorative approaches demonstrated sufficient mechanical strength to withstand functional and parafunctional occlusal loads under clinical conditions.

From a clinical perspective, these findings suggest that fracture resistance alone may not be the most critical determinant of restorative success when all tested materials provide resistance values well above the maximum physiological bite forces. Instead, the significantly higher proportion of favorable, repairable fracture patterns observed in the fiber-reinforced groups may represent a more meaningful clinical advantage, as such failures are more likely to preserve the remaining tooth structure and facilitate conservative retreatment. Consequently, polyethylene fiber reinforcement may offer clinical benefits through improving fracture behavior and failure mode rather than by increasing the ultimate load-bearing capacity of the restoration<sup>21</sup>.

From a practical perspective, handling characteristics and cost-effectiveness influence material selection. InFibra may offer advantages over conventional systems such as Ribbond due to its easier handling, compatibility with various adhesive systems, and reduced technique sensitivity. Additionally, its lower cost may enhance its applicability in routine clinical practice.

However, several limitations should be acknowledged. Although the present study was conducted in vitro, efforts were made to approximate clinical conditions, including artificial aging equivalent to 6

months, oblique stresses, and periodontal ligament simulation, which enhance the clinical relevance of the findings. Nevertheless, in vitro models cannot fully reproduce the complex intraoral environment, where variables such as multidirectional loading, patient-specific factors, and long-term fatigue behavior may influence outcomes. Additionally, while static load-to-fracture testing provides valuable comparative data, it may not fully reflect fatigue-driven failure mechanisms observed clinically. Furthermore, fiber placement remains technique-sensitive and may affect the reproducibility of results. Notably, this study provides comparative data on a newer polyethylene fiber system (InFibra), for which currently available evidence remains deficient, as most existing literature focuses on either short fiber systems or Ribbond.

Despite the comparable performance of InFibra and Ribbond observed in this study, the predominance of in vitro evidence and the lack of well-designed randomized clinical trials preclude definitive conclusions regarding the clinical superiority of polyethylene fiber reinforcement. Within the limitations of this study, fiber reinforcement should be considered a strategy for failure modulation rather than strength enhancement. These findings support a shift from strength-based restorative concepts toward a biomimetic, failure-controlled approach aimed at preserving tooth structure and improving long-term outcomes. Future long-term clinical studies are required to validate these findings and to better define the role of fiber reinforcement in restorative dentistry.

## Conclusion

Within the limitations of this in vitro study, polyethylene fiber reinforcement (InFibra and Ribbond) did not improve the fracture resistance of MOD composite restorations; however, both systems significantly promoted more favorable, repairable failure patterns. InFibra demonstrated performance comparable to Ribbond, suggesting its potential as a cost-effective alternative, although confirmation through well-designed clinical studies is needed.

## Declarations

### Contributions

Conceptualization, Esraa Esmeail, Dina Fayeze; Methodology, Esraa Esmeail, Dina Fayeze; Writing—original draft preparation, Dina Fayeze; Writing—review and editing, Esraa Esmeail; Funding acquisition, Esraa Esmeail, Dina Fayeze.

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### Ethics declarations

Competing interests

The authors declare no competing interests.

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## Data Availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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## Figures

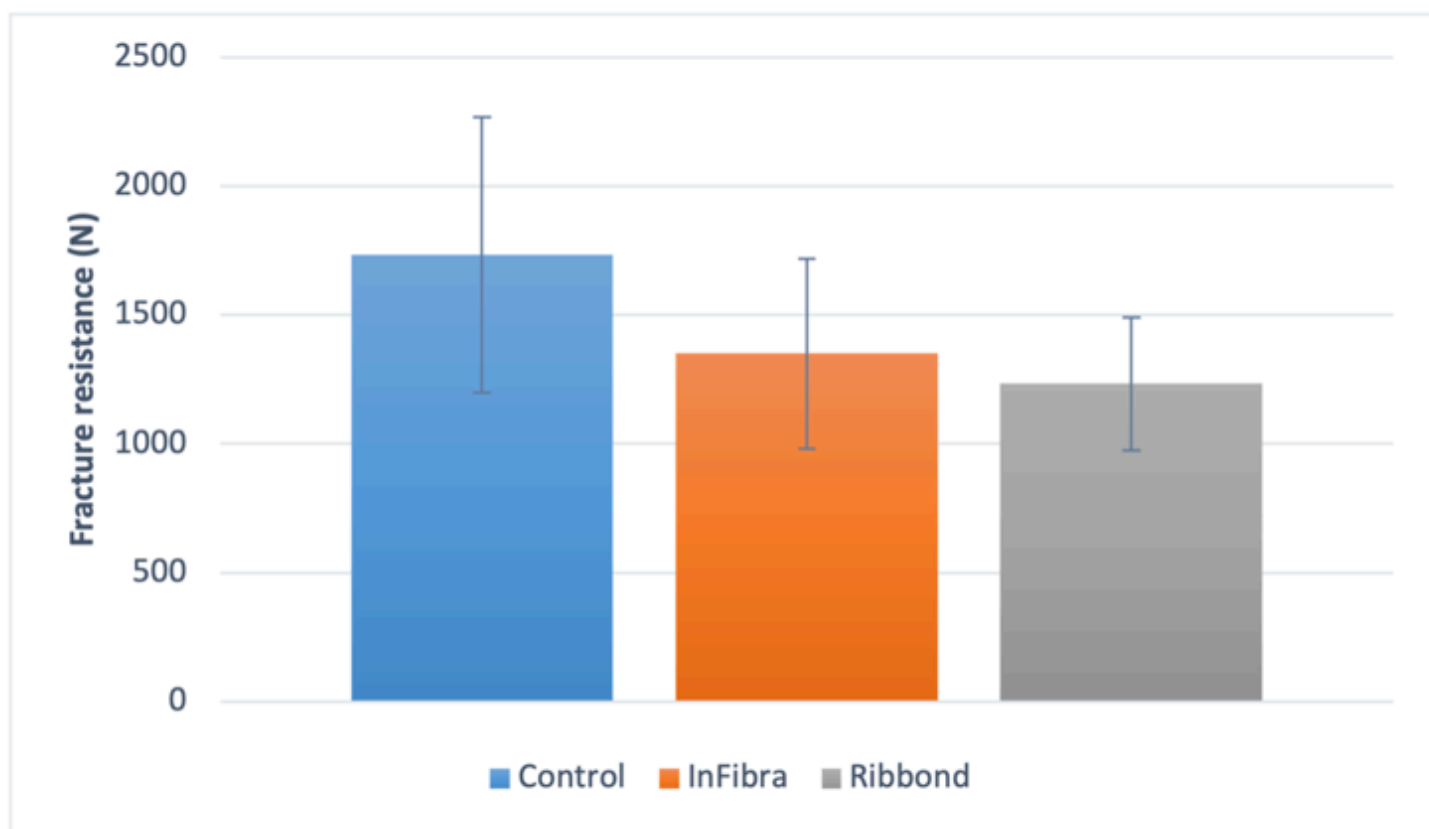


**Figure 1**

Bar chart showing mean and standard deviation (error bars) values for fracture resistance.

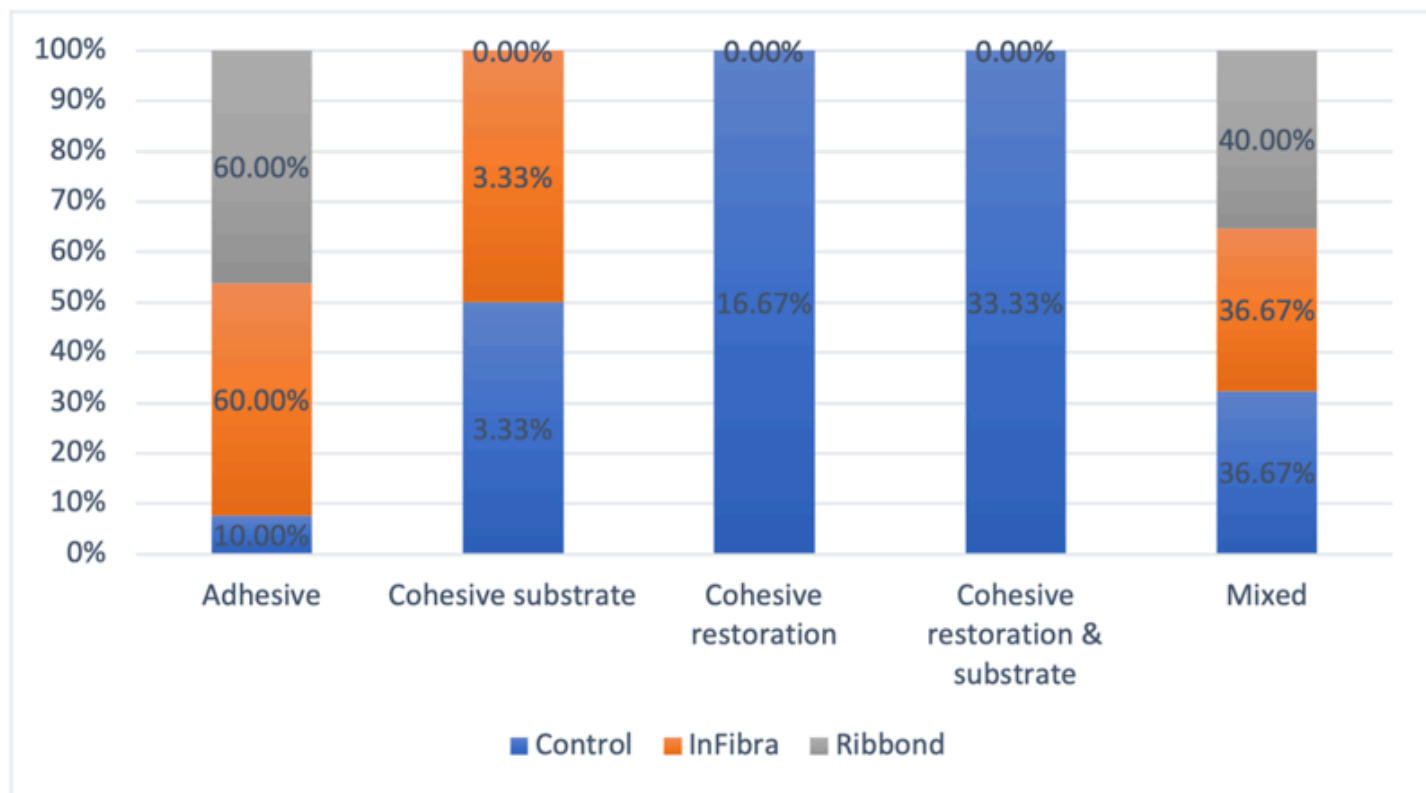


**Figure 2**

Stacked bar chart showing failure modes distribution (A).

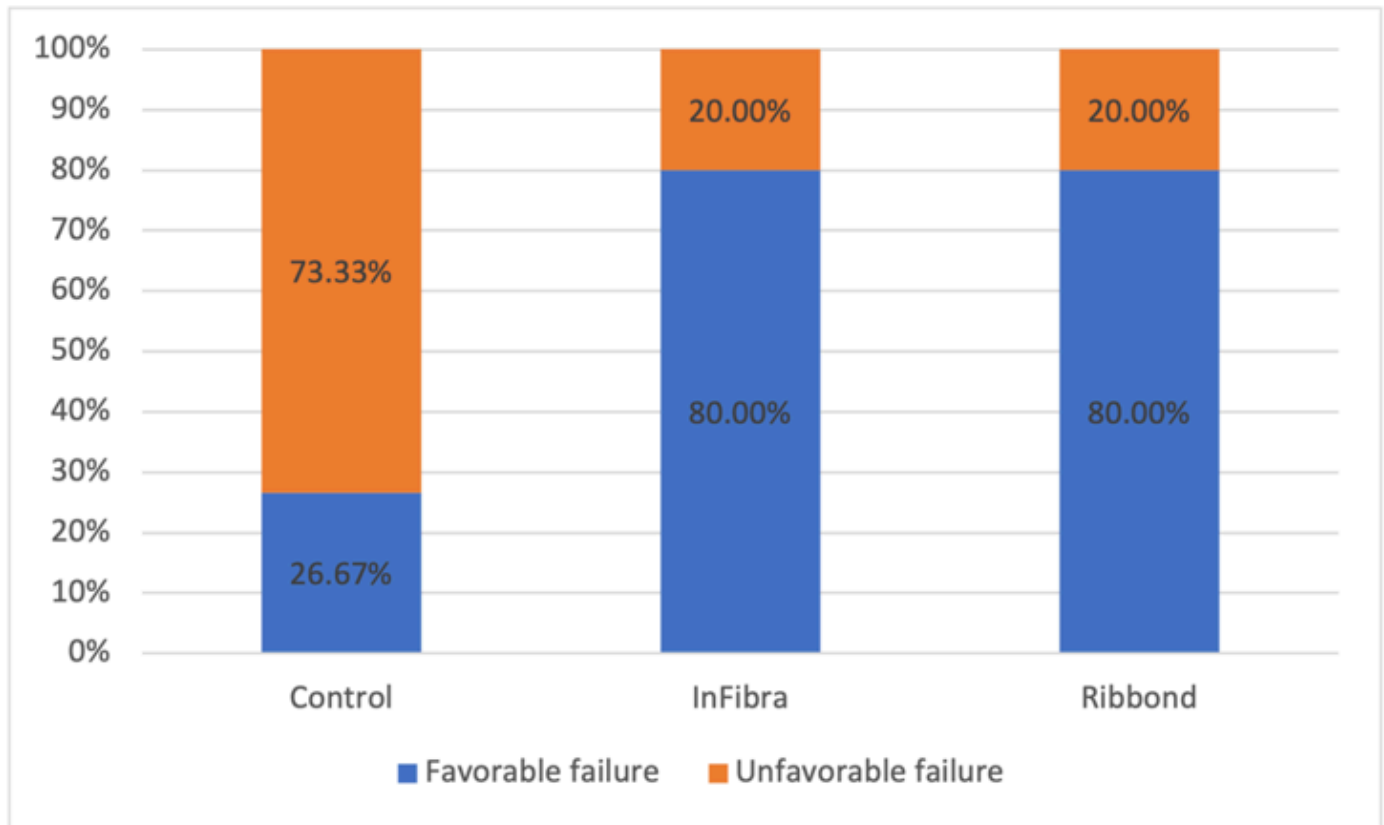


**Figure 3**

Stacked bar chart showing failure modes distribution (B).

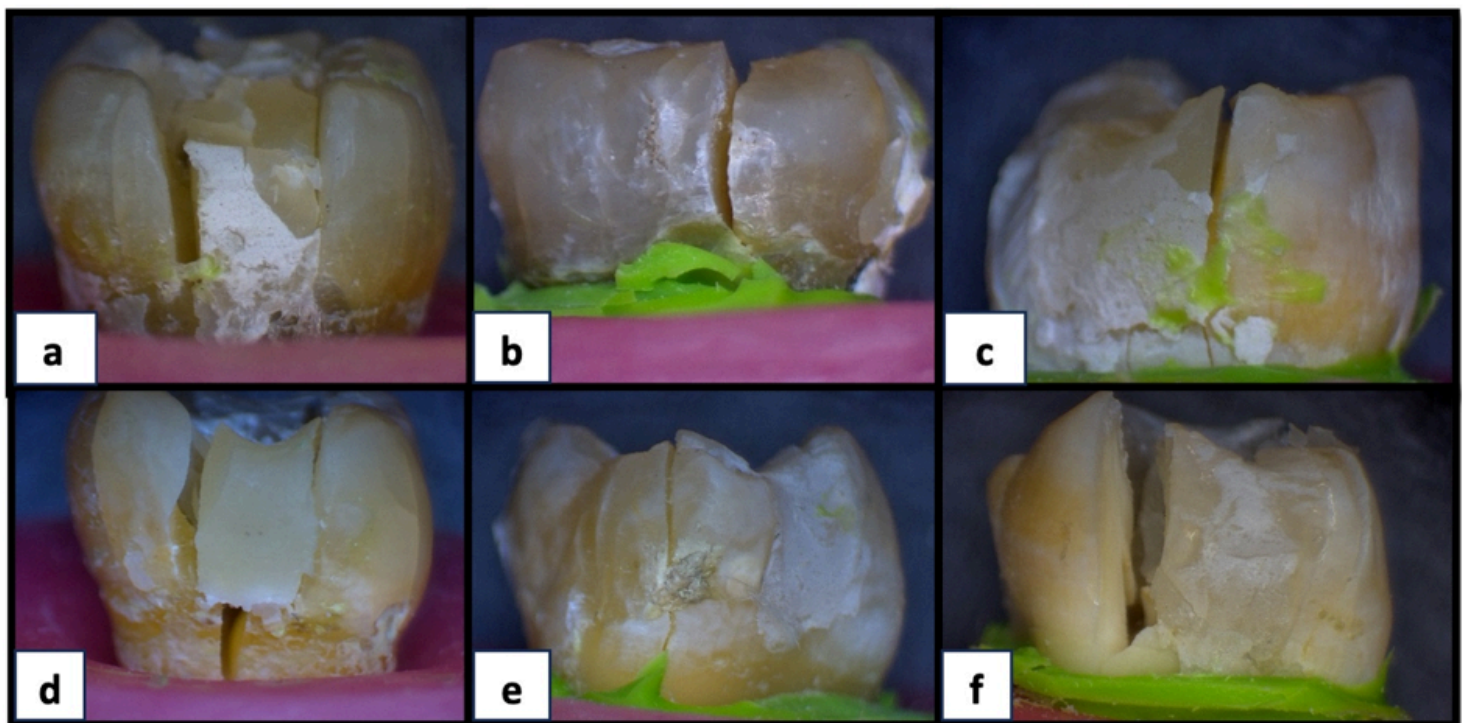


**Figure 4**

a) Adhesive failure characterized, b) Cohesive within restorative material, c) cohesive failure within the substrate, d) Mixed failure (adhesive + cohesive), e) Favorable Failure above CEJ, f) Unfavorable Failure below CEJ.