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Evaluation of the Fracture Resistance of Nanohybrid Composite Resin Resto rations in Complex Cavities Reinforced with Glass or Polyethylene Fibers

Evaluación de Resistencia a la Fractura de Restauraciones de Resina Compuesta Nanohíbrida en Cavidades Complejas Reforzadas con Fibras de Vidrio o Polietileno

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ABSTRACT: The aim of this study was to evaluate the efficacy of Interlig (INT) glass fiber and Ribbond (RIB) polyethylene in the fracture resistance of complex mesio-occluso-distal (MOD) class II restorations with nanohybrid composite resin (Z350XT). Forty sound human maxillary premolars were selected and prepared with dimensions of 2.5mm×3.0mm bucco-lingual and cervico-occlusal, respectively, using a #1014 diamond bur. After the adhesive protocol, the teeth were divided into 4 groups (n=10): CON- conventional restoration (Z350XT); RES- high-viscosity, high-fill flowable resin; INT- glass fiber laminate; RIB- polyethylene laminate. Following the different restorative protocols, fracture resistance tests were performed using a mechanical testing machine and fracture patterns were examined under a stereomicroscope. Fracture resistance data were analyzed using one-way ANOVA followed by Tukey's test ($P < 0.05$). INT and RIB showed higher fracture resistance values ($P < 0.05$), but were similar to each other ($P > 0.05$). There was no difference in fracture resistance between CON and RES ($P > 0.05$). Adhesive type fractures were the most frequent, and the unfavorable fracture pattern was higher in INT and RIB. Aesthetic restorations reinforced with glass or polyethylene fibers are more resistant to fracture, although they exhibit an unfavorable fracture profile.

KEY WORDS: fracture resistance, class II restorations, polyethylene, composite resin, fiberglass.

INTRODUCTION

Extensively destroyed cavities in posterior teeth present a significant challenge in restorative dentistry. The configuration of the cavity, especially when involving proximal walls, increases the susceptibility of the restoration to fracture (Bonilla *et al*., 2020). This is because the loss of the reinforcing structure, combined with the action of compressive and shear forces, and additional stresses caused by the polymerization shrinkage of resin materials, result in greater cuspal deflection (Nam *et al*., 2010; Escobar *et al*., 2023).

In an attempt to improve the biomechanical behavior and durability of composite resin restorations, studies have suggested the use of reinforcement with different types of fibers, applied directly and internally in cavity preparations (Scribante *et al*., 2018). Fiber-based devices can be employed as potential internal reinforcement for extensive direct composite resin restorations in both vital and endodontically treated teeth (Vallittu, 2018).

The reinforcing effect is based on the load-stress transfer from the polymer matrix to the fibers, acting as a stress dissipator and serving as a fracture prevention layer when subjected to loads (Vallittu, 2015). However, its efficacy depends on several variables, such as the type of composite used, the

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number of fibers in the resin matrix, the type, length, shape, and orientation of the fibers, as well as the adhesion to the polymer matrix and the resin impregnation into the fiber (Nam *et al*., 2010; Vallittu, 2015).

Interlig is a braided glass fiber (60 ± 5 % by weight), impregnated with light-curable composite resin (40 ± 5 % by weight) (Abdulamir & Majeed, 2023). It exhibits high tensile strength, low thermal conductivity, and adequate surface chemical resistance, allowing its adhesion to resin-based materials (Rana *et al*., 2021). The fibers are impregnated with light-curable composite resin, hence eliminating the need for any other type of adhesive or resin for impregnation (Abdulamir & Majeed, 2023).

Ribbond is a polyethylene fiber, composed of aligned polymeric chains with a low-density modulus, allowing for greater impact resistance (Abdulamir & Majeed, 2023). The architecture of the polyethylene fiber enables uniform force distribution in more than one direction (Miao *et al*., 2016). Fibers associated with composites can potentially neutralize the adverse effects of resin polymerization shrinkage and the resulting stress transferred to the composites and dental hard tissues (Aggarwal *et al*., 2018).

Despite the increasing use of biomimetic materials and their importance in clinical applicability, there is still a lack of *in vitro* comparative studies, which motivated the authors to conduct this study. Therefore, this study aimed to evaluate the effectiveness of glass reinforcement fibers (Interlig) and polyethylene fibers (Ribbond) in fracture resistance in complex mesio-occluso-distal (MOD) cavities using nanohybrid composite resin (Z350XT) as a restorative material.

To this end, the following hypotheses were tested: H01: the fracture resistance values of MOD cavity restorations with nanohybrid composite resin reinforced with glass fiber or polyethylene fiber do not differ from unreinforced composite restorations. H02: the fracture resistance values of MOD cavity restorations with nanohybrid composite resin reinforced with glass fiber and polyethylene fiber do not differ from each other.

MATERIAL AND METHOD

The present study was approved by the Research Ethics Committee (CAAE 68355317.0.0000.5416). Forty sound human upper premolars, extracted for orthodontic or prosthetic reasons, with single root and similar root anatomy, were selected, cleaned, and kept in a 0.1 % thymol solution at 4°C until use.

Specimen’s Preparation

After washing the teeth in distilled water for 2 hours to remove residues from the thymol solution, the roots were immersed in molten paraffin wax to provide the formation of a film around the root surface. Subsequently, the teeth were axially embedded in PVC tubes (20 mm internal diameter × 20 mm length) containing acrylic resin (Jet Clássico; Grandent, Niterói, RJ, Brazil), up to 3 mm short of the cemento-enamel junction. The vertical insertion of the teeth was verified with a parallelometer (Gnatus, São Carlos, SP, Brazil), and the assembly was allowed to rest for 24 hours for complete polymerization of the acrylic resin.

Next, the teeth were removed from the acrylic resin matrix, and the paraffin wax film was removed by immersion in heated water. A thin layer of polyether impression paste (Impregum Soft; 3M Espe, Sumaré, SP, Brazil) was applied to the root surface, and the teeth were reinserted into the acrylic matrix. The purpose of the thin film formed between the root and the acrylic resin matrix was to simulate the presence of the periodontal ligament.

Next, the specimens were adapted to a cavity preparation machine (APC 100; Odeme, Luzerna, SC, Brazil), and in each crown, a complex class II MOD cavity preparation was performed, with dimensions of 2.5 mm opening in the bucco-lingual direction and 3.0 mm depth cervico-occlusally, from the marginal ridge of the dental crown, using a #1014 diamond bur (KG Sorensen, Serra, ES, Brazil), driven by a high-speed handpiece, under constant cooling.

Once the preparations were completed, all crowns underwent selective enamel conditioning with phosphoric acid (Condac 37; FGM, Joinville, SC, Brazil) for 15 seconds and were rinsed with distilled water for 30 seconds. The entire surface of the cavity preparation was dried with absorbent paper points, and the adhesive primer (Clearfil SE Bond; Kuraray Noritake Dental Inc., Tokyo, Japan) was actively applied to the dentin surface in two layers, which were homogenized with gentle air blasts for 10 seconds. Immediately after, the adhesive (Clearfil SE Bond; Kuraray Noritake Dental Inc., Tokyo, Japan) was applied to both dentin and enamel, subjected again to gentle air blasts for 10 seconds, and photoactivated with an LED device (Valo; Ultradent, South Jordan, UT, USA), with a power of 1,200 mW/cm^2, for 20 seconds.

Restorative protocols

The specimens were randomly allocated into 4 groups (n = 10), according to the restorative protocol:

CON (conventional restoration): The specimens were restored with nanoparticulate composite resin (Z350XT; 3M Espe, Sumaré, SP, Brazil), shade A1B, in 1 mm increments and light-cured using an LED device (Valo; Ultradent, South Jordan, UT, USA) for 20 seconds after each increment. After the placement of the final increment, corresponding to the occlusal surface of the dental crown, the entire assembly was light-cured again for 60 s.

RES (high-viscosity fluid resin with filler content): After the application of adhesive to the dental crown, a increment of high-viscosity fluid composite resin with filler content (Grandioso Heavy Flow; Voco, Cuxhaven, Germany) was uniformly applied over the pulpal wall of the cavity preparation, with a thickness of 1 mm (Fig. 1A) and light-cured for 60 seconds using an LED device (Valo; South Jordan, UT, USA). Subsequently, the dental crown was restored identically as described in CON.

INT (glass fiber laminate): The application of adhesive and high-viscosity fluid composite resin with filler content was similar to that described in RES. Next, the glass fiber laminate (Interlig; Angelus, Lodrina, PR, Brazil) was impregnated with composite resin (Grandioso Heavy Flow; Voco, Cuxhaven, Germany) and adapted into the cavity preparation (Figs. 1B and 1C), covering the pulpal wall and 1mm of the buccal and palatal walls in the cervico-occlusal direction, light-cured for 20 seconds, and the aesthetic restoration was completed similarly to that described in CON.

RIB (polyethylene laminate): Similar to the description in INT, however, the polyethylene laminate (Ribbond; Oraltech, Ibiporã, PR, Brazil) was used (Figs. 1D-F). The specimens were immediately immersed in distilled water for 7 days at 37 °C. Table I shows the chemical composition, origin, and batch of the products used.

Fracture Resistance

Each specimen was subjected to axial force, with the crosshead adapted to the center of the dental crown, supported exclusively on the aesthetic restoration, in an electromechanical testing machine (EMIC; São José dos Pinhais, PR, Brazil), with a load cell of 5 kN, at a speed of 0.5 mm/min. The specimen's resistance was determined as the force (in N) required for fracture occurrence **(Figs. 2A-B).**

Type of Fracture

After conducting the fracture resistance test, the specimens were analyzed under a stereomicroscope, with a magnification of 10x, and the fracture pattern was classified as follows (Soto-Cadena *et al*., 2023): a. adhesive, when there was fracture at the interface between the composite resin restoration and the tooth structure; b. cohesive, when the fracture occurred exclusively within the composite resin restoration; c. mixed, when there was simultaneous occurrence of adhesive and cohesive fracture.

Table I. Materials used in the study.

Commercial name	Composition
Clearfil SE Bond Kuraray Noritake (Tokyo, Japan)	Self-etch primer: 10-MDP, HEMA, hydrophilic dimethacrylate, camphorquinone, water; Adhesive: 10-MDP, bis-GMA, HEMA, hydrophilic dimethacrylate, camphorquinone, silanated colloidal silica.
Filtek Z350XT 3M ESPE (St. Paul, MN,USA)	Bis-GMA, UDMA, TEGDMA, Bis-EMA, non-agglomerated/non-aggregated 20 nm silica filler, 4 to 11 nm zirconia filler, and aggregated zirconia/silica cluster filler.
Grandioso Heavy Flow Voco (Cuxhaven, Germany)	Monomers: Bis-GMA, Bis-EMA, TEGDMA; Fillers: (83 wt. %= 68 vol. %); glass ceramic (average particle size: 1µm), functionalized SiO_2 nanoparticles (from 20 to 40 nm).
Ribbond Oraltech (Ibiporã, Brazil)	Ultra-high molecular weight polyethylene.
Interlig Angelus (Lodrina, Brazil)	Bis-GMA resin, barium glass ceramics, highly dispersed silicon dioxide, catalysts, and pigments.

Bis-GMA, bisphenol A-glycidyl methacrylate; HEMA, 2-hydroxyethyl methacrylate; 10-MDP, 10-methacryloyloxydecyl dihydrogen phosphate; UDMA, dimethacrylate urethane; Bis-EMA, hydroxyethyl methacrylate bisphenol.

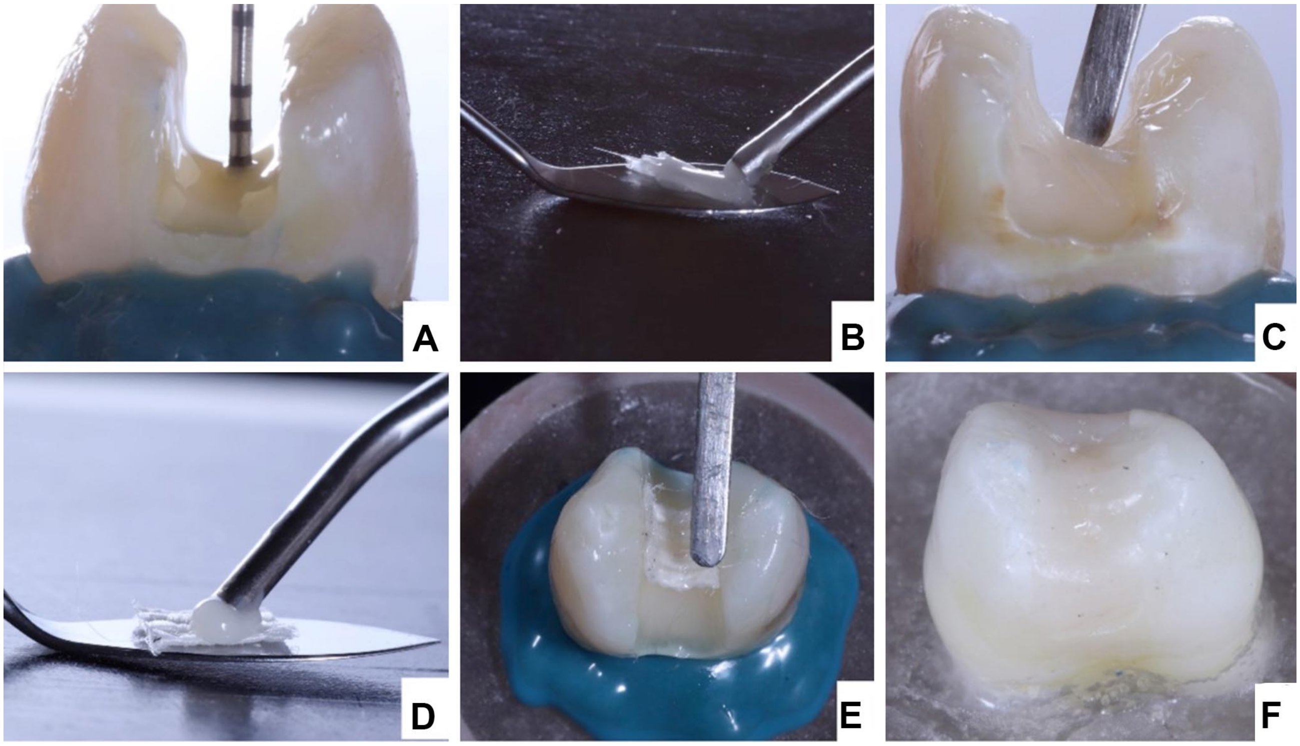

Fig. 1. A - 1mm of high-viscosity flowable resin. B - Wetting of the fiberglass. C - Positioning of the fiberglass in the cavity. D - Wetting of the polyethylene fiber with high-viscosity flowable resin. E - Positioning of the polyethylene fiber. F - Finalized restoration.

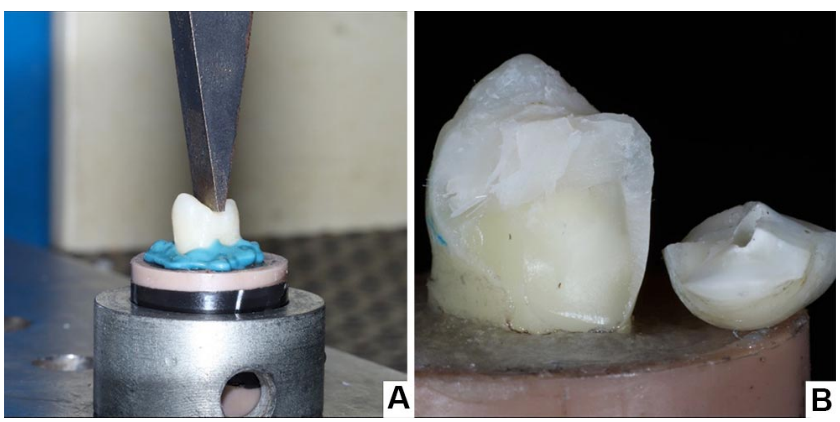

Fig. 2. Sample in mechanical testing machine. A - Tip for compression analysis in position. B - Fractured tooth after analysis.

Statistical Analysis. The data obtained in the fracture resistance evaluation were initially subjected to the Shapiro-Wilk test (p = 0.05) to confirm the normal distribution of the results. Then, they were analyzed using one-way ANOVA and subsequently by Tukey's test (P < 0.05).

The analysis of fracture type and pattern were descriptive and expressed as frequencies based on the evaluated group.

Fracture Pattern

The fracture pattern after conducting the fracture resistance test was classified as follows: a: favorable, when the fracture occurred 1 mm short of the cemento-enamel junction, and b: unfavorable, when the fracture occurred more than 1 mm away from the cemento-enamel junction.

RESULTS

Fracture resistance. INT and RIB showed higher fracture resistance values (P < 0.05), but were similar to each other (P > 0.05). There was no difference in fracture resistance between CON and RES (P > 0.05). Table II shows the mean, standard deviation,

Table II. Arithmetic mean, standard deviation, and confidence interval of fracture resistance values (in kN), according to the MOD cavity restoration method.

	CON	RES	INT	RIB
m (sd)	1.44 (0.24) B	1.51 (0.34) B	2.01 (0.37) A	2.19 (0.45) A
Ci	1.62 ≤ μ ≤ 1.27	1.74 ≤ μ ≤ 1.26	2.26 ≤ μ ≤ 1.74	2.51 ≤ μ ≤ 1.88

AB, Different letters indicate significant differences (P < 0.05). CON, Control; RES, Restoration; INT, Interlig; RIB, Ribbond. m, arithmetic mean; sd, standard deviation; ci, confidence interval.

and confidence interval of the fracture resistance values (in N), according to the restorative treatment protocol.

Table II shows the mean, standard deviation, and confidence interval of the fracture resistance values (in N), according to the MOD cavity restoration methods.

Type and pattern of fracture: The adhesive fracture type was the most frequent, regardless of the restorative protocol used. The mixed fracture type occurred only in INT and RIB. The unfavorable fracture pattern was higher in INT and RIB. On the other hand, in CON and RES, there was no difference in the incidence of fracture patterns.

Table III shows the incidence of fracture type and pattern (in %) in dental crowns after the fracture resistance test, according to the restorative protocols.

Table III. Incidence of fracture type and pattern (in %) in dental crowns after the fracture resistance test, according to the restorative protocols.

		CON	RES	INT	RIB
type of fracture	adhesive	70	80	60	70
	cohesive	30	20	20	0
	mixed	0	0	20	30
fracture pattern	favorable	50	50	40	40
	unfavorable	50	50	60	60

CON, Control; RES, restoration; INT, interlig; RIB, ribbond.

DISCUSSION

The results of this study demonstrated that restorations with nanohybrid composite resin reinforced with fiberglass or polyethylene showed higher fracture resistance in MOD cavities compared to restorations without fiber, rejecting the null hypothesis H01. However, the fracture resistance was similar between the groups that used fiberglass and polyethylene reinforcement, accepting H02.

In this study, the fracture resistance test was employed to determine the load limits that the restorations, with or without fiber, would withstand before failing. Initially, restorations without fiber were performed using a high-viscosity and highly filled flowable composite (Grandioso Heavy Flow, 83 wt. % = 68 vol. %) (Jager *et al*., 2016) as a liner beneath the conventional composite layer (RES), to evaluate the final performance of the restoration under axial force. The data from the present investigation did not reveal statistically significant differences when RES was compared to non-reinforced composite restorations (CON).

Despite the strong recommendations for using flowable resin materials in thin layers (1 to 2 mm) on the bottom wall in direct restorations (de Carvalho *et al*., 2021) to mitigate polymerization stresses and reduce the risk of gaps forming between the adhesive layer and the dental substrate (de Carvalho *et al*., 2021), the technique did not show an influence when the aim was to evaluate fracture resistance in MOD restorations. It is known that the significantly lower fracture toughness of composites compared to dentin renders the polymer unable to stop crack propagation (Deliperi *et al*., 2017; Garoushi *et al*., 2018; Alshabib *et al*., 2019), which possibly occurred in this study.

In contrast, fiber-reinforced composites demonstrated higher fracture resistance, regardless of the type of fiber, although no significant difference was observed between them. The stress transfer from the polymer matrix of the composite resin to the fiber devices can explain these results. Due to their high tensile strength, the fibers can reduce the stress transmitted to the remaining dental structure (Agrawal *et al*., 2022). Furthermore, despite the structural differences between the fibers, both devices are able to promote good load distribution within the composite resin restoration (Sáry *et al*., 2019; Agrawal *et al*., 2022; Albar & Khayat, 2022).

Although fiber-reinforced restorations exhibit greater fracture resistance, the results for the fracture pattern were unfavorable (more than 1mm from the cementoenamel junction) and involving a functional cusp (Fig. 2), contradicting the findings of Jafari Navimipour *et al*. (2012) who demonstrated a favorable fracture pattern (60 %). Despite using the same Interlig device in both studies, the authors placed the fiberglass circumferentially in the MOD cavity of premolars with treated canals, which may account for the discrepant results.

Ribbond features a fiber design based on a dense network of locked nodal intersections, with intertwined fibers changing the crack direction, ultimately dissipating stress (Deliperi *et al*., 2017). Scotti et al. (2016) demonstrated that the primary fracture line partially deviates upon encountering the fiber layer, following the horizontal direction of the fibers. However, this effect is not sufficient to prevent catastrophic failure. It is possible that the change in fracture direction promoted by the fibers contributed to an unfavorable fracture pattern, occurring with a frequency of 60 % (Table III).

This study has some methodological limitations, such as the use of dehydrated teeth and the performance of tests immediately after the restorations. Therefore, it is essential to conduct long-term evaluations to investigate the effects of durability and stability of the restorations under conditions that simulate the oral environment. Additionally, the exclusive use of tests with axial force indicates the need for studies that assess the impact of restorations under oblique force.

Finally, the authors suggest the development of fibers with an improved geometric design to promote more effective force distribution.

CONCLUSION

Aesthetic restorations reinforced with fiberglass or polyethylene are more resistant to fracture, although they exhibit an unfavorable fracture profile.

Ethics approval statement: This study was conducted in accordance with all the provisions of the local human/animal subjects oversight committee guidelines and policies approval by Sao Paulo State University (Araraquara).

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RESUMEN: El objetivo de este estudio fue evaluar la eficacia de la fibra de vidrio Interlig (INT) y el polietileno Ribbond (RIB) en la resistencia a la fractura de restauraciones complejas mesio-ocluso-distales (MOD) clase II con resina compuesta nanohíbrida (Z350XT). Se seleccionaron y prepararon cuarenta premolares maxilares humanos sanos con dimensiones de 2,5 mm $\times$ 3,0 mm vestibulolingual y cervicoclusal, respectivamente, utilizando una fresa de diamante n.º 1014. Después del protocolo adhesivo, los dientes se dividieron en 4 grupos (n=10): CON- restauración convencional (Z350XT); RES-resina fluida de alta viscosidad y alto relleno; INT-laminado de fibra de vidrio; RIB- laminado de polietileno. Siguiendo los diferentes protocolos de restauración, se realizaron pruebas de resistencia a la fractura utilizando una máquina de prueba mecánica y se examinaron los patrones de fractura bajo un estereomicroscopio. Los datos de resistencia a la fractura se analizaron mediante ANOVA unidireccional seguido de la prueba de Tukey (P <0,05). INT y RIB mostraron valores de resistencia a la fractura más altos (P <0,05), pero fueron similares entre sí (P > 0,05). No hubo diferencias en la resistencia a la fractura entre CON y RES (P > 0,05). Las fracturas de tipo adhesivo fueron las más frecuentes y el patrón de fractura desfavorable fue mayor en INT y RIB. Las restauraciones estéticas reforzadas con fibras de vidrio o polietileno son más resistentes a la fractura, aunque presentan un perfil de fractura desfavorable.

PALABRAS CLAVE: resistencia a la fractura, restauraciones clase II, polietileno, resina compuesta, fibra de vidrio.

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