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Comparative Study of Continuous Polyethylene Fibers Reinforced with Composite Resins: An in Vitro Study

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ABSTRACT

Polyethylene continuous fiber is noted for its excellent mechanical properties, being used as reinforcement in dental restorations. When combined with composite resins, it offers high tensile strength, which allows it to withstand high forces without fracturing due to its flexibility. This material is also resistant to corrosion and chemicals, and comes in various forms, such as sheets, tubes or wires, which broadens its applications. The objective of the study was to evaluate which experimental group presents the best mechanical properties under compression. A mixed descriptive, cross-sectional and experimental methodology was used. The results showed that group 2, composed of R+S ribbond and silane, presented the highest values of compressive strength. The use of appropriate protocols, together with materials such as silane and everX in composite resins, significantly improves compressive strength.

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Introduction

Dental restoration is a fundamental dental procedure involving the repair of teeth damaged by caries or trauma, using durable materials such as ceramics, cements, composites and certain metals. The development of dental materials has advanced significantly, with a particular focus on composite resins, which have proven to be an effective alternative for restorations in both anterior and posterior teeth, due to their superior mechanical and esthetic properties [1].

Composite resins or composites are synthetic materials that have evolved substantially to improve their strength, translucency, and opacity, making them more similar to natural teeth [2]. Originally limited to esthetic applications in anterior teeth, research has allowed these resins to be used in posterior restorations, even replacing metal amalgams due to their improved mechanical and esthetic properties. The resins are composed of an organic matrix, an inorganic filler and a bonding agent. Bisphenol-A glycidyl methacrylate (BIS-GMA) is one of the most common monomers in the organic matrix, known for its high viscosity and low shrinkage during polymerization [3].

Research on composite resins has been driven by the need to improve the physical and biological properties of these materials. Antibacterial properties and remineralization capabilities are key aspects in dental restorations, as they contribute to preventing recurrent caries and improving the longevity of restorations [1]. Advances in these fields have resulted in resins that are not only more esthetic, but also offer better protection against dental caries and promote regeneration of dental tissues.

In terms of antimicrobial activity, composite resins use two main mechanisms: interaction with bacterial proteins and disruption of the cell membrane, which prevents bacterial adhesion and DNA synthesis [4]. These characteristics are essential for prolonging the lifetime of restorations. In addition, the incorporation of remineralizing agents, such as calcium phosphates, has improved the ability of resins to promote dental tissue regeneration [5].

In this context, reinforcement fibers have emerged as an effective solution to improve the mechanical properties of resins. These fibers, which can be oriented three-dimensionally, help to increase the elastic modulus of resins and improve their tensile strength, providing increased durability in clinical procedures [6]. Ultra-high molecular weight polyethylene fibers, in particular, have proven to be very effective due to their tensile and impact strength, which improves load distribution and reduces the possibility of fractures [7].

The use of polyethylene fibers in dental restorations has been extensively studied, showing good results in direct restorations that require the use of large amounts of composite resins [8]. These chemically inert fibers present adhesion challenges with the polymer matrix, which has led to the implementation of high-energy plasma treatments to improve bonding [6]. However, the effectiveness of this bonding tends to decrease with time, underscoring the importance of further research in this area.

Another fundamental aspect in dental restorations is the use of bonding agents, such as silane, which improve the adhesion between the fibers and the polymer matrix. Silane acts as an intermediary agent that improves surface wetting and promotes a stronger chemical bond between the resin and fibers [9]. Good adhesion

is crucial for load transfer between the polymeric matrix and the reinforcing fibers, which ensures increased durability of restorations under occlusal forces.

The use of Ribbond fibers in dentistry began in 1992, when they were promoted as an effective material for reinforcing composite resins. These plasma-treated, ultra-high molecular weight polyethylene fibers are arranged in a three-dimensional cross-linked pattern that improves their stability, durability, and shear strength [10]. Their three-dimensional structure also minimizes fiber displacement during handling, which helps prevent the formation of microfractures during the resin polymerization process [11].

In addition to fibers, nanomaterials have begun to play an important role in modern dentistry. Nanocomponents used in dental fillings have improved the antiwear, antifungal, and antibacterial properties of resins, which has represented a significant advance in restorative dentistry [12]. Despite these advances, further clinical studies are still needed to evaluate the toxicity and long-term effects of these nanomaterials [13].

In the field of dental materials research, mechanical testing is essential to ensure that the materials used meet the necessary requirements for clinical restorations. These tests make it possible to evaluate the tensile strength, flexural strength and hardness of polymers, as well as their ability to withstand the stresses applied during mastication [14]. In dentistry, the evaluation of these properties is crucial to ensure that materials can be properly manipulated and offer prolonged durability [15].

Current research is focused on improving the physical, mechanical and biological properties of composite resins to increase their efficacy in dental restorations. The use of reinforcing fibers, bonding agents such as silane and the incorporation of nanomaterials has shown promise, but more research is still needed to optimize these materials and their long-term clinical performance.

Materials and Methods

The materials used in this study included glycerin, glass slabs, resin spatula, tweezers, Ribbond scissors, applicators, polishing discs and a contra-angle handpiece. For the light curing process, a VALO lamp (Ultradent, USA) was used. 3M Filtek Z350 nano hybrid resin (3M, USA) was used, with a total of 8 g of composite resin, divided into two tubes of 4 g each. In addition, a tube of PermaSeal (Ultradent, USA) and silane (Ultradent, USA) were used. Ribbond fibers (Ribbond, USA) were also used, with a total of 64 mm of fiber, divided into 4 mm for 16 samples distributed in 4 groups, and everX (Japan) as an additional component.

To perform the test in this research, a random, simple and probabilistic sample of 16 resin blocks of cylindrical shape, with a diameter of 7 mm and a height of 3 mm was used, following the specifications of the ISO 4049 standard [16]. The samples were divided into 4 groups, distributed as follows

- Resin + Ribbond + Permaseal + Resin.
- Resin + Ribbond + Silane + Resin
- Resin + everX + Ribbond + Permaseal + Resin
- Resin + everX + Ribbond + Silane + Resin

The objective of this configuration was to compare the compressive and flexural strength of the experimental composite resin samples.

Obtaining Samples

Group 1 (G1): Resin + Ribbond + Permaseal + Resin

To make the 4 tablets that made up this group, a strip of celluloid was placed in the mold to ensure that the top and bottom surfaces were parallel. Initially, a 1.48 mm layer of 3M Z350 resin was added to the bottom. Then, on a glass tile, 4 mm of Ribbond fiber was cut with the same brand of scissors. Next, a drop of Permaseal was applied on the fiber, ensuring its complete impregnation. Subsequently, the impregnated fiber was placed in the center of the resin with tweezers, followed by the addition of another 1.48 mm layer of resin. In this way, the combination of resin and Ribbond reached a height of approximately 3 mm. Once the material was placed in the mold, it was light cured with the VALO GRAND LED lamp for 20 seconds on both sides, following the manufacturer's instructions, with an intensity of 1100 mW/cm². Finally, the ingots were removed from the mold and polished to eliminate any imperfections.

Group 2 (G2): Resin + Ribbond + Silane + Resin

In the same manner as the previous group, a strip of celluloid was placed in the mold to ensure that the top and bottom surfaces were parallel. First, a 1.48 mm layer of 3M Z350 resin was added to the bottom. Then, on a glass tile, 4 mm of Ribbond fiber was cut with the same brand of scissors. A drop of silane was then applied to the fiber, ensuring complete impregnation, and allowed to dry for 1 minute. Subsequently, the impregnated fiber was placed in the center of the resin with tweezers, followed by another 1.48 mm layer of resin. In this way, the combination of resin and Ribbond reached a height of approximately 3 mm. Once the material was placed in the mold, it was light cured with the VALO GRAND LED lamp for 20 seconds on both sides, following the manufacturer's instructions, with an intensity of 1100 mW/cm². Finally, the ingots were removed from the mold and polished to eliminate any imperfections.

Herculite (Kerr) Resin with Super-Snap (SHOFU) Polishing Discs
The mold was cleaned with alcohol and petroleum jelly was applied. The Herculite resin was placed in the 4 mm x 1 mm and 2 mm thick matrix in increments. After covering the cavity, the excess was removed with a glass slab. The material was light cured on both sides with the LED lamp (≥1100 MW/cm²) for 10 seconds. A layer of glycerin was applied and photopolymerized again. Excess glycerin was removed and polished using Super-Snap discs, following the same grain order as for the Forma resin.

Herculite Resin (Kerr) with Diamond Pro Polishing Discs (FGM)
To make the 4 tablets in this group, a strip of celluloid was placed in the mold to ensure that the top and bottom surfaces were parallel. A 1.48 mm layer of 3M Z350 resin was added to the bottom. Then, on a glass tile, 4 mm of Ribbond fiber was cut with the same brand of scissors. A drop of silane was then applied to the fiber, ensuring complete impregnation, and allowed to dry for 1 minute. Subsequently, an everX resin increment was made on the lower and upper parts, forming a "sandwich" type structure, and distributed in the center with a resin spatula. The impregnated fiber was placed in the center of the resin with tweezers, followed by another 1.48 mm layer of resin, reaching a height of approximately 3 mm. Once the material was placed in the mold, it was light cured with a VALO GRAND LED lamp (Ultradent, USA) for 20 seconds on both sides, following the manufacturer's instructions, with an intensity of 1100 mW/cm². Finally, the ingots were removed from the mold and polished to eliminate any imperfections.

Compressive Strength

The compressive strength tests were carried out at the materials evaluation laboratory (LEMAT). They were placed in the AG-IS universal machine, the load cell was 10 kN and the speed was 1.3 mm/min according to ASTM D635 test standards [17].

Scanning Electron Microscopy (SEM)

The samples were taken to the national public health research institute (INSPI). Prior to analysis, two cuts were made on each sample. The specimens, consisting of resin lozenges, were mounted on metal rods, using double-stick carbon tape for fixation. Subsequently, the teeth were thinly coated with a gold film, applying a discharge for 20 seconds on each tooth, with the aim of increasing electron emission. The samples were observed and analyzed using a JEOL_ JSM-IT500LV scanning electron microscope. To document the results, electron micrographs were taken with an exposure time of 100 seconds per image, using the JSM-IT500LV System Backup Data MP-69010LVUEXCS Installer MP-96040EXCS software for image processing.

Results and Discussion

Compressive Strength

Group 1 showed an average maximum load of 16.1494 kN, an average maximum strain of 16.7765%, and an average maximum displacement of 0.49250 mm. The results shown in Table 1 and Figure 1 indicate that this group of resins presented good resistance to both load and deformation; however, the resistance to displacement was lower in comparison.

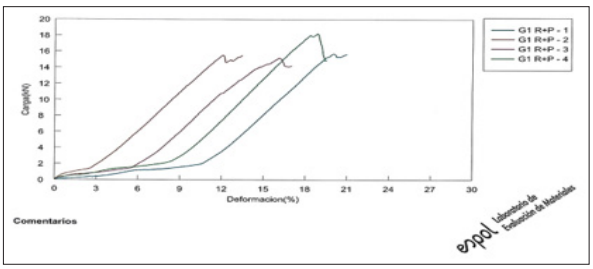

Figure 1: Load vs Deformation Graph of Group 1.

Group 2 obtained an average maximum load of 16.9981 kN, an average maximum deformation of 18.8406%, and an average maximum displacement of 0.56350 mm (Table 2 and Figure 2). The results show that this group presented better compressive strength values, with a remarkable resistance to both load and deformation, and good behavior in terms of displacement.

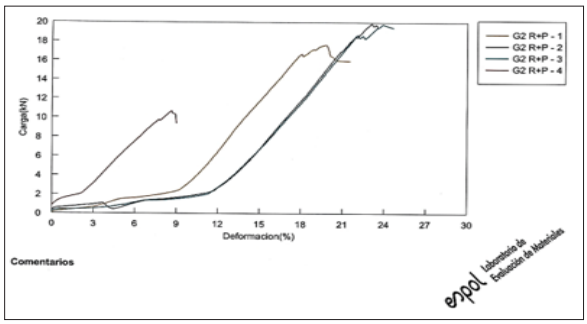

Figure 2: Load vs Deformation Graph of Group 2.

Group 3, composed of 4 tablets, obtained an average maximum load of 15.1950 kN, an average maximum deformation of 19.4573%, and an average maximum displacement of 0.59550 mm (Figure 3 and Table 3). The results indicate that this group showed the best resistance to displacement and deformation, although it presented the lowest resistance to load among all the groups evaluated.

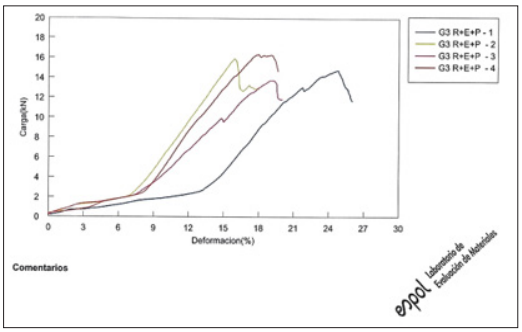

Figure 3: Load vs Deformation Graph of Group 3.

Group 4, composed of 4 tablets, obtained an average maximum load of 15.9234 kN, an average maximum deformation of 13.9265%, and an average maximum displacement of 0.41650 mm (Table 4 and Figure 4). The results show that this group presented the lowest values in both displacement and deformation, and ranked third in load resistance. However, in general terms, it was the group that showed the lowest values among all the samples evaluated.

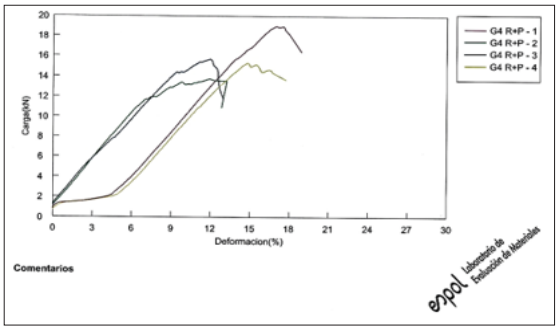

Figure 4: Load vs Deformation Graph of Group 1.

The results show that the values obtained in the resins with polyethylene fibers (Ribbond), have higher values in relation to the supported load and deformation, which translates into higher flexural strength and fracture toughness and low values of displacement, which allows reducing the polymerization shrinkage. The values are similar to those of the research by Puertas et al [18].

On the other hand, it was found that the deformation value in the parts of the group worked with resin + everX + ribbond + silane + resin, was much lower than the other groups. The values were similar to those obtained by Vivek et al [19].

With respect to the asd tables, it can be inferred that, through the tests carried out, the groups worked with silane obtained better values in relation to the supported load, deformation and displacement. This is due to the fact that silane offers better adhesive strength on treated surfaces [9], [20].

SEM

Figure 5 shows that (a) shows a panoramic view of the polyethylene fiber at 500 microns, surrounded by the bonding agent and resin. In (b) and (c), at 50 and 10 microns respectively, details of the polyethylene fiber with Permaseal particles attached are visualized. Finally, in (d), at 5 microns, the arrangement of the long continuous fibers and their adhesion to the bonding agent can be seen in more detail. No internal microfractures were detected, although gaps were observed between the fiber and the Permaseal.

Table 1: Results of Group 1.

	Max_Load (kN)	Max_Strain (%)	Max_Displacement(mm)
G1 R+P - 1	15.6984	20	0.566
G1 R+P -2	15.5119	12.0779	0.372
G1 R+P - 3	15.1584	16.1538	0.462
G1 R+P - 4	18.2288	18.8742	0.57
Mean	16.1494	16.7765	0.4925
Standard Desviation	1.40425	3.52401	0.0946

Table 2: Results of Group 2.

	Max_Load (kN)	Max_Strain (%)	Max_Displacement (mm)
G2 R+P - 1	17.64	19.7636	0.602
G2 R+P -2	19.8919	23.112	0.658
G2 R+P - 3	19.8019	23.8636	0.714
G2 R+P - 4	10.6584	8.6233	0.28
Mean	16.9981	18.8406	0.5635
Standard Desviation	4.3527	7.0408	0.1944

Table 3: Results of Group 3.

	Max_Load (kN)	Max_Strain (%)	Max_Displacement (mm)
G3 R+E+P - 1	14.7497	24.7592	0.771
G3 R+E+P -2	15.9347	15.9068	0.478
G3 R+E+P - 3	13.7231	19.1533	0.561
G3 R+E+P - 4	16.3725	18.0101	0.572
Mean	15.195	19.4573	0.5955
Standard Desviation	1.197	3.7816	0.1243

Table 4: Results of Group 4.

	Max_Load (kN)	Max_Strain (%)	Max_Displacement (mm)
G4 R+P - 1	18.9769	17.0413	0.508
G4 R+P -2	13.7269	11.9503	0.356
G4 R+P - 3	15.6694	11.9463	0.356
G4 R+P - 4	15.3206	14.7682	0.446
Mean	15.9234	13.9265	0.4165
Standard Desviation	2.2042	2.4655	0.0743

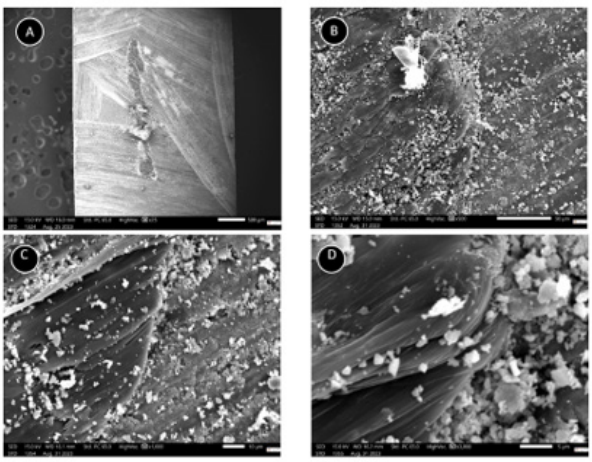

Figure 5: SEM micrograph of Group 1.

Figure 6 shows the micrograph of G2, where in (a) a panoramic view shows a fracture on the external side of the resin, while internally no fractures are detected. In (b), at 50 microns, the three elements of this group are visualized: fibers, silane and resin, with some spaces between the fiber and the resin. In (c), at 10 microns, an optimal bond between the fiber, silane and resin is seen, which explains the better results obtained by this experimental group, despite the gaps observed in image (b).

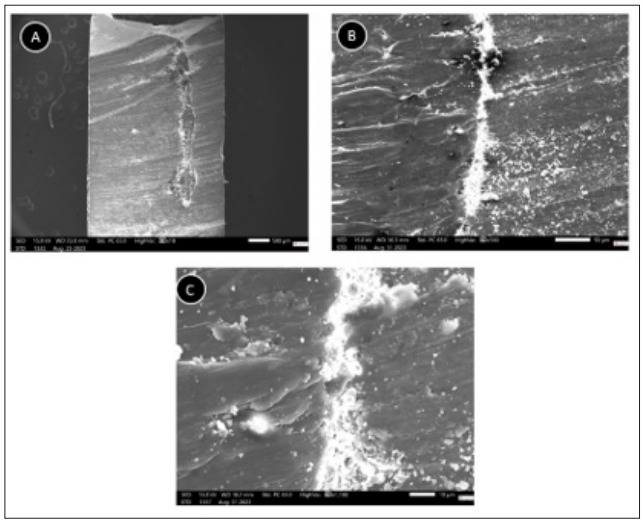

Figure 6: SEM Micrograph of Group 2.

Figure 7 shows SEM micrographs of G3. In (a) is an overview at 200 microns of the fiber with its bonding agents, with no evidence of microfractures near the fiber. In (b), at 20 microns, the fibers are observed together with their bonding agents, with multiple gaps between the permaseal and everX. Images (c) and (d), taken at 10 microns in different areas, show the presence of permaseal and everX; in (c) a higher number of bonding agents is observed, while in (d) these are found in smaller proportion. In general, not many permaseal particles were detected in the fibers.

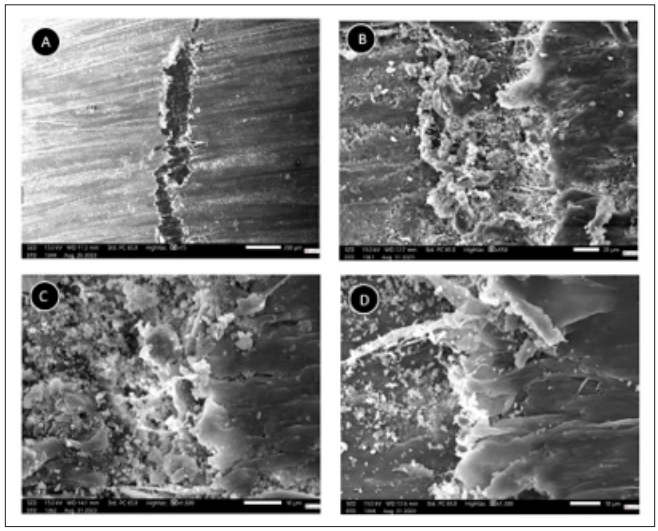

Figure 7: SEM Micrograph of Group 3.

Figure 8 presents SEM micrographs of G4. In images (a) and (b), taken at 500 and 200 microns respectively, large fractures can be seen in this group, along with the polyethylene fiber and its bonding agents. Image (c), at 50 microns, shows more clearly the continuous fibers, everX filaments, and their silane bonding. Finally, in (d), at 10 microns, the fibers are seen in greater detail, together with the presence of resin particles, silane and fiber.

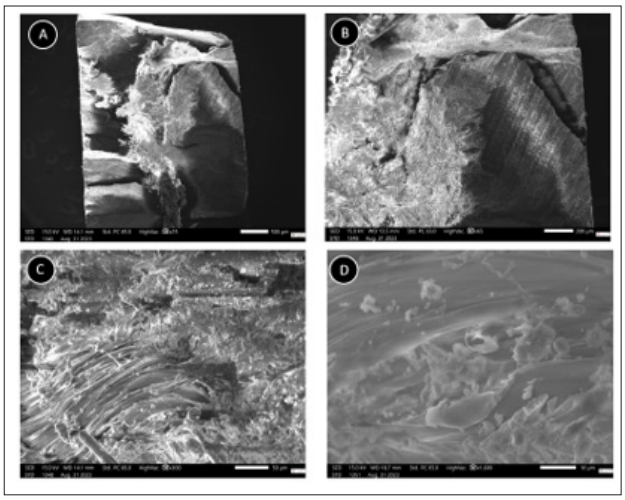

Figure 8: SEM Micrograph of Group 4.

Conclusions

The results obtained in this study indicate that the addition of silane to polyethylene fibers significantly improves the physical and mechanical properties of the composite resins, particularly the modulus of elasticity. The samples treated with silane and everX presented better performance compared to those incorporating permaseal. Scanning electron microscopy (SEM) analysis allowed observing details at the microscopic level, such as fiber networks intertwined with the inorganic fillers of the composite resins. No significant differences were observed between the bonding agents (silane and permaseal), due to the covalent and chemical nature of the bonds formed.

Regarding the protocol used for in vitro compression studies in polymers, the samples must comply with the requirements of ISO 4049, both for molds and dental pieces, and follow the normative parameters established to guarantee the validity of the results in dental studies.

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Conflict of Interest: The author declares that there are no conflicts of interest related to this study.

The author gave their final approval and agreed to be accountable for all aspects of the work.

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