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Comparison of the mechanical properties and depth of cure of bulk-fill and bioactive composite resins*

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ABSTRACT

Objective: To compare *in vitro* the mechanical properties and depth of cure of bioactive bulk-fill resins versus bulk-fill composite resins. **Materials and methods:** An *in vitro* experimental study was conducted with 48 blocks of three types of resin. Each block received a load of 500 g for 30 seconds and was photopolymerized with a VALO® Cordless-Ultradent unit (1500 mW/cm^2) for 4 seconds. Microhardness was evaluated using the Vickers hardness test, employing a calibrated LG® HV-1000 hardness tester. For statistical analysis, the Student's t-test and the non-parametric Kruskal-Wallis test were applied, considering statistical significance if $p < 0.05$. **Results:** The bioactive resin Beautifil® Bulk (BB) showed the highest microhardness, reaching a mean value of 55.1 VH ($p < 0.01$), followed by the resins Tetric® N-Ceram Bulk Fill (TNCBF) with 44.9 VH and Tetric® N-Flow Bulk Fill (TNFBF) with 28.8 VH. The TNFBF bulk-fill resin showed the highest compressive strength, with a mean of 222.4 MPa ($p < 0.01$), compared to 173.5 MPa for the TNCBF moldable resin and 129.7 MPa for the flowable BB resin. All three resins achieved a homogeneous mean curing depth of 4.0 mm ($p > 0.05$). **Conclusions:** The BB bioactive resin showed greater microhardness compared to moldable and flowable bulk-fill resins, while the TNFBF flowable bulk-fill resin showed the highest compressive strength. All three resins had similar values in terms of curing depth.

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INTRODUCTION

The main disadvantages of composite resins used to restore posterior teeth affected by dental caries, trauma, other conditions include polymerization shrinkage and the associated stress, as well as a limited depth of cure—factors that may favor secondary caries. In addition, the procedure requires a meticulous technique and precise working time to ensure optimal results in a clinical environment where efficiency is essential. The development of composite resins dates back to the 1960s with the introduction of the hybrid monomer BIS-GMA, an innovation that revolutionized the field by enabling faster polymerization and lower shrinkage compared to methyl methacrylate (1). Nevertheless, material shrinkage may compromise the adhesive interface and varies with the composition and volume of the resin (2).

Over time, various components have been incorporated into composite resins, to optimize light intensity for photopolymerization and using the incremental layering technique in 2-mm increments; however, results have been only partially successful (3). To shorten restoration time, bulk-fill composites were introduced, for single-increment placement of 4-5 mm, reducing bubble formation, particularly in deep posterior restorations (4). Although microhardness improvements and procedural efficiency have been observed, further advances are still expected in both clinical and laboratory settings (5). Several studies have evaluated the limitations of conventional and bulk-fill composite, leading to the development of new restorative materials with remineralizing and bactericidal properties (6), alongside newer light-curing units with programs tailored to restoration type and technique (7). Nonetheless, depth of cure remains as one of the main factors that can compromise the effectiveness of bulk-fill and bioactive composites.

Glass ionomer cements (GICs) have been used for restorations in low-stress areas because of their anticariogenic effect. However, they have limitations in physical and esthetic properties compared to composites (8). To overcome these drawbacks, several modifications have been developed, such as resin-modified glass ionomers (RMGI), Equia®, Giomer®, and Ormocer®, among others. Although these innovations have shown partial improvements, they still do not match the performance of conventional composites. Commercial composites generally exhibit little or no antibacterial activity; indeed, the release of triethylene glycol dimethacrylate and related monomers has been hypothesized to promote cariogenic bacterial growth. In the case of compomers, which are designed to release fluoride, the released amount is minimal and their antibacterial effect decreases considerably after the first 24 hours (9).

The introduction of nanomaterials in dentistry was primarily aimed at improving caries prevention and control. The incorporation of nanofiller particles in composite resins, ranging from 5 to 100 nm in size, has not only enhanced their esthetics through color optimization but also increased their strength (10). One of the main purposes of using nanomaterials has been to improve mechanical properties, including wear resistance, microhardness, and the reduction of polymerization shrinkage, thereby contributing to greater durability of restorations (11). Currently, composite resins must be formulated to minimize polymerization shrinkage, since this phenomenon generates microleakage and favors the recurrence of caries. To address this limitation, aesthetic restorative materials incorporating nanoparticles with antibacterial properties—such as chlorhexidine, chitosan, metallic particles, and ciprofloxacin, among others—have been investigated (12).

Bioactive materials—such as GICs and RMGIs—were developed to reduce stress at the tooth–restoration interface, minimize microleakage, and prevent recurrent caries (13). These materials chemically adhere to tooth structure, releasing fluoride, and exerting antibacterial effects (14). Bioactive materials have been designed to confer additional properties to composite resins, enhancing their clinical functionality. Among them, ACTIVATM BioACTIVE stands out as a bioactive coating material that incorporates a bioactive matrix capable of releasing and recharging fluoride, calcium, and phosphate. Its mechanism of action responds to pH changes, and its physical and mechanical properties are comparable to those of natural dental tissues (15). Likewise, Beautifil® Bulk, a nanohybrid giomer-based composite resin containing surface pre-reacted glass (S-PRG) filler particles, combines the benefits of bulk-fill resins with the bioactive properties of glass ionomer (16). Given the limited evidence on bioactive resins, this study aimed to compare *in vitro* the mechanical properties and depth of cure of bulk-fill composite resins versus a bioactive resin. The null hypothesis stated that there were no significant differences between the two materials.

MATERIALS AND METHODS

An *in vitro* experimental study was conducted and approved by the Ethics Committee of the Faculty of Stomatology at Universidad Nacional de Trujillo (PIB EST-014-2024). Three groups were formed, each comprising 16 resin cylinders selected according to predefined criteria (Table 1):

- Group 1: Bioactive resin *Beautifil® Bulk* (BB) – Shofu® Inc.
- Group 2: Sculptable composite resin Tetric® N-Ceram Bulk Fill (TNCBF) – Ivoclar Vivadent®
- Group 3: Flowable composite resin Tetric® N-Flow Bulk Fill (TNFBF) – Ivoclar Vivadent®

Table 1. Resins used in the study.

Resin (code, shade, lot)	Type	Filler	Monomer	Photoinitiator
Beautifil® Bulk (C125A, A2, 042368)	Bioactive nanohybrid	Surface pre-reacted glass-ionomer (S-PRG) bioactive glass microparticles	Bis-GMA TEGDMA	CQ
Tetric® N-Ceram Bulk Fill (0123, AIV, Z051PT)	Bulk-fill nanohybrid	Inorganic particles (barium glass, strontium glass, prepolymerized aluminum oxide, and silicon oxide)	Bis-GMA UDMA	Ivocerin, CQ
Tetric® N-Flow Bulk Fill (0123, AIV, Z051YY)	Bulk-fill nanohybrid	Inorganic particles (barium glass, strontium glass, prepolymerized aluminum oxide, and silicon oxide)	TEGDMA UDMA	Ivocerin, CQ

Bis-GMA: bisphenol A-glycidyl methacrylate; TEGDMA: triethanolamine dimethacrylate; CQ: camphorquinone; UDMA: urethane dimethacrylate.

Resin cylinders with standard dimensions of 6×4 mm were prepared, excluding those that showed any type of defect or damage prior to measurement. The sample size for each group was determined using the probabilistic random sampling formula, suitable for comparing two or more groups in a quantitative variable, with a 95% confidence level and 80% statistical power.

Sample preparation

Condensation-type heavy silicone molds with central openings of 6 mm in diameter were used for the preparation of specimens with a thickness of 4 mm (17). Molds were placed on a glass slide and a celluloid strip, then filled with each of the three resins. To prevent oxygen inhibition, the upper surface of the mold was covered with a second celluloid strip. To ensure adequate compaction of the resin block, a 500 g load was applied for 30 seconds. Subsequently, the specimens, previously organized in their respective groups, were photopolymerized from the upper surface using a high-power light-curing unit (VALOTM Cordless-Ultradent) at 1500 mW/cm^2 for 4 seconds. The LED unit lens was positioned at the center of the specimen, in direct contact with the second celluloid strip. The intensity of the lamp was verified with an LED radiometer.

Microhardness measurement

Surface microhardness was measured using the Vickers hardness test, employing an LG® microhardness tester, model HV-1000, previously calibrated and certified. Three indentations were made on the top and bottom surfaces (500 g, 15 s). Results were expressed as Vickers hardness (HV).

Compressive strength measurement

Compressive strength was determined in megapascals (MPa) using a digital universal testing machine (LG®, model CMT-5L), previously calibrated and certified. Each sample was positioned vertically on the base of the device, and a constant load of 100 kN was applied at a speed of 1 mm/min until reaching the fracture point.

Evaluation of depth of cure

Depth of cure was evaluated following ISO Standard 4049 for resin-based filling and luting materials. Cylinder height was measured in millimeters (mm) using a digital Vernier caliper with a precision of 0.01 mm. Each sample was labeled with indelible ink and stored in an incubator at 37 °C, in complete darkness, for 24 hours to prevent any additional polymerization induced by exposure to ambient light after photocuring.

Statistical analysis

Data were processed using an automated tabulation pattern with the SPSS-26 statistical package (IBM® SPSS Inc., Chicago, IL, USA). The results were presented in statistical tables according to the study objectives. Group comparisons used the nonparametric Kruskal-Wallis test; $p < 0.05$ was considered statistically significant. Pairwise comparisons used Mann-Whitney tests with Bonferroni adjustment.

RESULTS

The bioactive resin BB showed the highest Vickers microhardness values (55.1 HV). The Kruskal-Wa-

llis test indicated a highly significant statistical difference compared with TNCBF (sculptable) and TNFBF (flowable) resins, the latter showing the lowest Vickers microhardness values. The complementary analysis confirmed differences in mean microhardness among the resin types when compared in pairs (Table 2).

Table 2. *In vitro* Vickers microhardness of flowable bulk-fill resin, sculptable bulk-fill resin, and bioactive resin.

Indicator (HV)	Type of resin			Kruskal-Wallis test
	Bioactive bulk (A)	Sculptable bulk-fill (B)	Flowable bulk-fill (C)	
Mean	55.1	44.9	28.8	K-W = 49.8
Median	54.3	44.8	29.1	p = 0.000
1st quartile	53.5	43.5	27.1	
3rd quartile	56.2	46.0	30.4	
Post hoc test[1]				
A vs. B		p = 0.004**		
A vs. C		p = 0.000**		
B vs. C		p = 0.004**		

[1] Mann-Whitney test with Bonferroni adjustment.
**p < 0.01

For compressive strength, mean values differed notably among resins. The Kruskal-Wallis test found sufficient evidence to declare a highly significant statistical difference. The nanohybrid resin TNFBF showed the highest compressive strength (222.4 MPa) compared with the TNCBF resin and the bioactive resin BB, which exhibited the lowest value. The complementary analysis indicated significant differences in compressive strength among the resin types when compared pairwise (Table 3).

Regarding depth of cure, all three evaluated resins (BB, TNCBF, and TNFBF) achieved homogeneous values, with no statistically significant differences (p > 0.05) (Table 4).

Table 3. *In vitro* compressive strength of bioactive, sculptable bulk-fill, and flowable bulk-fill resins.

Indicator (MPa)	Type of resin			Kruskal-Wallis test
	Bioactive	Sculptable bulk-fill	Flowable bulk-fill	
Mean	129.7	173.5	222.4	K-W = 29.5
Median	115.3	181.9	218.6	p = 0.000
1st quartile	106.6	158.2	207.4	
3rd quartile	158.8	191.1	232.9	
Post hoc test[1]				
A vs. B		p = 0.010**		
A vs. C		p = 0.000**		
B vs. C		p = 0.039*		

[1] Mann-Whitney test with Bonferroni adjustment.
**p < 0.0; *p < 0.05

Table 4. *In vitro* depth of cure of bioactive, sculptable bulk-fill, and flowable bulk-fill resins.

Indicator	Type of resin			Kruskal-Wallis test
	Bioactive (A)	Sculptable bulk-fill (B)	Flowable bulk-fill (C)	
Mean	4.0	4.0	4.0	K-W = 2.00
Median	4.0	4.0	4.0	p = 0.367
1st quartile	4.0	4.0	4.0	
3rd quartile	4.0	4.0	4.0	
Post hoc test[1]	Not applicable. No statistically significant difference was found.			

[1] Mann-Whitney test with Bonferroni adjustment.
p > 0.05

DISCUSSION

Composite resins have gained popularity in dentistry; however, controversies remain regarding mechanical properties and the completeness of polymerization. To address these challenges, bulk-fill composite resins have been developed, designed for large restorations that promise efficient polymerization and optimal properties in thicknesses greater than 2 mm. In the present study, the mechanical properties and depth of cure were compared *in vitro* among a bioactive resin, a sculptable bulk-fill resin, and a flowable bulk-fill resin, all from well-known brands recognized in the national market (Shofu® and Ivoclar Vivadent®). The selection of restorative materials must consider their mechanical properties to maximize clinical durability. In this context, *in vitro* evaluation of these properties is essential, as it allows simulation of resistance to wear and fracture (5).

In microhardness testing, the bioactive BB resin exhibited the highest value (55.1 HV) compared with TNCBF (sculptable) and TNFBF (flowable) resins. The Kruskal-Wallis test revealed statistically significant differences among the groups, which may be related to the type and size of the filler particles in the bioactive resin, as well as the presence of calcium, phosphate, and fluoride ions, which strengthen enamel and promote hydroxyapatite formation. These findings partially align with the study by Samuel et al. (18), who reported that fiber-reinforced bulk-fill resins had higher microhardness, followed by bulk-fill bioactive and conventional bulk-fill resins, suggesting that material composition influences clinical performance. On the other hand, Musavinasab and Norouzi (19) indicated that, although bulk-fill and bioactive resins allow application in large increments, none achieves its maximum hardness in deep restorations. Similarly, Saati et al. (20) highlighted that compositional differences significantly affect the microhardness of these materials.

Compressive strength is a key factor in posterior restorations, as it ensures structural stability under masticatory forces. In this study, the flowable bulk-fill TNFBF resin showed the highest compressive strength (222.4 MPa), followed by the sculptable bulk-fill TNCBF (173.5 MPa) and the bioactive BB resin (129.7 MPa). The Kruskal-Wallis test showed highly significant statistical differences, demonstrating that at least one resin exhibited compressive strength significantly different from the others. Differences may reflect variation in filler fraction particle morphology/size, and matrix composition. In contrast, Leprince et al. (3) concluded that bulk-fill resins generally have inferior mechanical properties compared to conventional high- and low-viscosity resins, and thus may not be recommended for high-occlusal-load restorations. According to Strini et al. (5), variability in bulk-fill resin composition can lead to differences in their mechanical properties in *in vitro* analyses, highlighting the need for long-term clinical studies to evaluate their real performance in the oral cavity.

The introduction of bulk-fill resins addresses the need to reduce restoration times, allowing application in increments of 4-5 mm. However, concerns persist about curing efficacy at depth—also relevant to bioactive systems placed in bulk. Increased thickness and light attenuation (reflection, scattering, absorption) can reduce the polymerization rate, affecting physical, mechanical, and biological performance. In this study, the three resins (BB, TNCBF, and TNFBF) achieved similar depths of cure, with no statistically significant differences. Similar results were reported by Parasher et al. (21), who compared the depth of cure of three commercial bulk-fill resins (X-tra Fil®, Tetric EvoCeram® Bulk Fill, and Beautifil® Bulk Restorative) and found no significant differences; however, individual values showed that the bioactive Beautifil® Bulk Restorative resin exhibited a lower depth of cure, attributed to differences in its composition, especially the type of light activator used.

A limitation of this study is that, being *in vitro*, it provides valuable information about material quality but does not fully reflect behavior in the oral cavity, where factors such as humidity, temperature, masticatory forces, saliva, and bacteria may influence performance and durability. Long-term clinical studies are required to evaluate the performance of these resins under real conditions and to further investigate aspects such as photopolymerization protocols, mechanical strength, and bioactivity. Additionally, future research should prioritize the study of postoperative sensitivity, longevity, and new formulations that optimize the strength and bioactivity of these restorative materials.

CONCLUSIONS

The bioactive composite resin exhibited higher microhardness than the sculptable and flowable bulk-fill composites, whereas the flowable bulk-fill showed the highest compressive strength. All materials met the required depth of cure for bulk-fill restorations.

Conflict of interest:
The authors declare no conflict of interest.

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Author contributions:
CMRA: conceptualization, methodology, research, writing – original draft.
MCRC: formal analysis, validation, writing – review & editing.
TERC: conceptualization, methodology, supervision, writing - review & editing.

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