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Original Article

Clinical performance of a bioactive Bulk-Fill restorative system compared with the conventional incremental resin composite technique in deep posterior cavities: a 12-month split-mouth clinical study

Desempenho clínico de um sistema restaurador bioativo bulk-fill comparado à técnica incremental com resina composta em cavidades posteriores profundas: estudo clínico split-mouth com acompanhamento de 12 meses

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Resumo

Objetivo: Avaliar o desempenho clínico em curto prazo (12 meses) de uma técnica restauradora bulk-fill comparada à técnica incremental convencional com resina composta em cavidades posteriores profundas, com materiais contendo partículas de vidro ionomérico pré-reagido. **Material e método:** Neste estudo clínico preliminar de boca dividida, 31 restaurações Classe I e II foram realizadas em cavidades posteriores profundas de 13 pacientes; os 10 pacientes que receberam as duas técnicas (27 restaurações) foram incluídos na comparação pareada. A alocação da técnica não foi randomizada e baseou-se na extensão da cavidade. As restaurações foram realizadas com resina composta nanohíbrida pela técnica incremental (grupo convencional) ou com um único incremento de resina bulk-fill recoberto pela mesma resina nanohíbrida (grupo bulk-fill). Após 12 meses, quatro examinadores calibrados avaliaram as restaurações segundo os critérios clínicos da Federação Dentária Internacional. Utilizou-se o teste de Wilcoxon pareado, com o paciente como unidade de análise ($\alpha = 0,05$). **Resultado:** Não foram detectadas diferenças estatisticamente significativas entre as técnicas para nenhum critério estético, funcional ou biológico ($p > 0,05$). Nenhuma restauração necessitou de substituição; uma restauração do grupo convencional recebeu escore 4 em critérios estéticos e foi repolida. Não foram observadas lesões de cárie com necessidade de tratamento, sensibilidade pós-operatória ou complicações endodônticas. **Conclusão:** Dentro das limitações deste estudo preliminar e não randomizado, não foram detectadas diferenças estatisticamente significativas entre as técnicas bulk-fill e incremental convencional em cavidades posteriores

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profundas após 12 meses. Esses achados não demonstram equivalência, sendo necessários estudos clínicos randomizados de longo prazo e com amostras maiores.

Descritores: Resinas compostas; restauração dentária permanente; materiais dentários; ensaio clínico.

Abstract

Objective: To evaluate the short-term (12-month) clinical performance of a bulk-fill restorative technique compared with a conventional incremental resin composite technique in deep posterior cavities, using restorative materials containing surface pre-reacted glass-ionomer fillers. **Material and method:** In this preliminary split-mouth clinical study, 31 Class I and II restorations were placed in deep posterior cavities of 13 patients; the 10 patients who received both techniques (27 restorations) were included in the paired comparison. Allocation of the technique was not randomized and was based on cavity extent. Restorations were placed either incrementally with a nanohybrid resin composite (conventional group) or with a single bulk-fill increment covered by the same nanohybrid resin composite (bulk-fill group). After 12 months, four calibrated examiners evaluated the restorations according to the World Dental Federation clinical criteria. Data were analyzed using the paired Wilcoxon signed-rank test, with the patient as the unit of analysis ($\alpha = 0.05$). **Result:** No statistically significant differences were detected between the techniques for any esthetic, functional, or biological criterion ($p > 0.05$). No restoration required replacement; one restoration in the conventional group received a score of 4 for esthetic criteria and was repolished. No caries lesions requiring treatment, postoperative sensitivity, or endodontic complications were observed. **Conclusion:** Within the limitations of this preliminary, non-randomized study, no statistically significant differences were detected between the bulk-fill and conventional incremental techniques in deep posterior

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cavities after 12 months. These findings do not demonstrate equivalence, and longer-term randomized clinical studies with larger samples are needed.

Descriptors: Composite resins; dental restoration, permanent; dental materials; clinical trial.

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INTRODUCTION

Resin composites are the materials of choice for the direct restoration of posterior teeth because they combine favorable mechanical properties, reliable adhesion to dental substrates, and satisfactory esthetic outcomes while preserving sound tooth structure[1–5]. Their longevity depends on material-, operator-, and patient-related factors, and restoration failure is more commonly associated with operative technique and adhesive procedures than with the restorative material itself[2,6–8].

The clinical criteria proposed by the World Dental Federation (FDI) provide a standardized method for evaluating the esthetic, functional, and biological outcomes of direct restorations[9], and longitudinal clinical studies support their use for assessing restorative outcomes[7–14].

Restorative procedures in deep posterior cavities are technically demanding[5]. The incremental technique has demonstrated satisfactory long-term clinical performance and remains the reference approach for direct posterior restorations[6,11,15–19]. Bulk-fill resin composites were introduced to simplify this procedure by allowing placement in thicker increments with adequate depth of cure, reduced polymerization shrinkage stress, and shorter chairside time[3,4,20].

Some bulk-fill resin composites incorporate surface pre-reacted glass-ionomer (S-PRG) fillers, which have been shown in laboratory studies to release multiple ions and to exhibit acid-buffering properties. However, the clinical relevance of these properties has not been established, and clinical evidence regarding S-PRG-based bulk-fill materials in deep posterior cavities remains limited[5,21]. Recent clinical studies have reported similar short-term outcomes for bulk-fill and conventional incremental techniques[22,23], but few have evaluated S-PRG-based bulk-fill materials in deep cavities using the FDI criteria[16,21], and methodological heterogeneity among studies makes comparison of the available evidence difficult[4,19,20].

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Therefore, the aim of this preliminary split-mouth clinical study was to compare the short-term (12-month) clinical performance of restorations placed in deep posterior cavities involving the inner third of the dentin (Black's Class I and II) using two S-PRG-based restorative materials applied with either the bulk-fill or the conventional incremental technique, according to the FDI clinical criteria. The null hypothesis was that there would be no significant differences in esthetic, functional, or biological performance between the two techniques after 12 months.

MATERIAL AND METHOD

ETHICAL APPROVAL AND STUDY DESIGN

The study was approved by the Research Ethics Committee of the University Center of Rio Preto (UNIRP), Brazil, under approval number 5,249,089. All participants provided written informed consent before the clinical procedures were initiated. This preliminary prospective split-mouth clinical study was designed to evaluate the clinical performance of two restorative techniques in posterior teeth with deep cavities extending to the inner third of the dentin, classified as Black's Classes I and II.

Each participant included in the comparative analysis received at least one deep restoration with each restorative technique, thereby serving as their own control. Consequently, intraindividual comparisons were performed using a split-mouth study design, thereby reducing the influence of individual biological and behavioral variability on restorative performance.

For analytical purposes, the restorations were categorized into two groups according to the restorative technique used. The conventional group (CG) consisted of restorations placed exclusively with the nanohybrid resin composite Beautifil II LS (Shofu, Kyoto, Japan) using the incremental technique in oblique increments of up to 2 mm, each individually light-cured for 40 seconds. The bulk-fill group (BG) consisted of restorations placed using Beautifil Bulk

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Restorative (Shofu, Kyoto, Japan) in a single increment of up to 4 mm, covered with a 2-mm superficial layer of Beautifil II LS. Both materials were light-cured for 40 seconds.

The restorative materials used in this study, including their manufacturers, physicochemical characteristics, shades (A2 and A3), and batch numbers, are presented in Table 1.

Table 1. Materials used in the experimental groups, including their manufacturers, types, and main compositions

Material (Batch)	Manufacturer	Type	Main Composition
Beautifil II LS (batch: 022390)	Shofu Inc., Kyoto, Japan	Nanohybrid resin composite with fluoride release and recharge	Bis-GMA; TEGDMA; S-PRG filler (fluoro-boro-alumino-silicate glass); pigments; polymerization initiators; and other components
Beautifil Bulk Restorative (batch: 122265)	Shofu Inc., Kyoto, Japan	Bulk-fill resin composite with six-ion release and fluoride recharge	Organic matrix comprising Bis-GMA, UDMA, Bis-MPEPP, and TEGDMA; S-PRG filler (fluoro-boro-alumino-silicate glass); polymerization initiators; pigments; and other components
BeautiBond Xtreme (batch: 082227)	Shofu Inc., Kyoto, Japan	Universal self-etch adhesive	Acetone; distilled water; Bis-GMA; acidic monomer; TEGDMA; silane coupling agent; and other components

*Bis-GMA, bisphenol A glycidyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate; Bis-MPEPP, bisphenol A polyethyleneglycol diether dimethacrylate; S-PRG, surface pre-reacted glass-ionomer filler composed of fluoro-boro-alumino-silicate glass particles capable of releasing fluoride, strontium, aluminum, sodium, and borate ions.

Source: Data obtained from the instructions for use and technical data sheets provided by the manufacturer (Shofu Inc., Kyoto, Japan).

SAMPLE SELECTION AND ELIGIBILITY CRITERIA

Permanent posterior teeth requiring direct restorations in deep cavities were eligible for inclusion. Only teeth with restoration margins located entirely in enamel were included. Eligible teeth exhibited no secondary caries, spontaneous pain, signs of irreversible pulpal involvement, or pathological tooth mobility (≥ Grade 1 according to Miller's classification). In

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addition, all teeth presented healthy periodontal tissues, antagonist teeth, and permitted adequate rubber dam isolation throughout the restorative procedure.

Teeth with extensive structural loss precluding direct restoration, subgingival carious lesions, root fractures, or pathological tooth mobility (≥ Grade 1 according to Miller's classification) were excluded. Patients with active bruxism, inability to attend follow-up appointments, or incomplete clinical records were also excluded. No a priori sample size calculation was performed. The sample consisted of all consecutive patients who met the eligibility criteria, were treated at the dental school clinic of the University Center of Rio Preto (UNIRP), and attended the 12-month recall examination. In total, 31 deep restorations placed in 13 patients were evaluated and are described in Table 3. Ten of these patients received at least one deep restoration with each technique (27 restorations: CG, n = 14; BG, n = 13) and were included in the paired comparison; the remaining three patients received deep restorations with the bulk-fill technique only and were therefore included in the descriptive analysis only. Given the small sample, the present study should be regarded as preliminary.

RESTORATIVE PROCEDURES

All procedures were performed by calibrated fourth- and fifth-year dental students under direct faculty supervision following standardized clinical protocols. This methodological approach enabled evaluation of the restorative materials under conditions representative of routine clinic practice in teaching clinics. Initially, prophylaxis was performed using pumice and water, followed by rubber dam isolation of the operative field.

CAVITY PREPARATION

Cavity preparation was performed according to the clinical condition of each tooth to be restored. In teeth affected by carious lesions, tissue removal followed the principles of

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minimally invasive dentistry, with selective removal of infected dentin while preserving affected dentin wherever possible[24,25]. In cases requiring the replacement of pre-existing restorations, the restorative material was completely removed, and the cavity preparation refined to eliminate the defective material and compromised tissue.

All included cavities extended to the inner third of the dentin and were therefore classified as deep cavities. Cavity depth was determined by clinical and radiographic evaluation based on the extent to which the lesion or restoration reached the inner third of the dentin. In Class I restorations, depth was determined from the pulpal wall, whereas in Class II restorations, it was determined at the axial wall, including compound and complex cavity preparations.

Initial cavity refinement was performed using diamond burs (KG Sorensen, Cotia, São Paulo, Brazil). The cavity walls were subsequently regularized with tungsten carbide round burs (KG Sorensen, Cotia, São Paulo, Brazil) under copious water cooling. Any remaining carious dentin was removed with manual dentin excavators (Golgran, São Caetano do Sul, São Paulo, Brazil).

MATRIX AND WEDGE PLACEMENT

For Class II cavities, a metal matrix was used in conjunction with a Tofflemire matrix holder and wooden wedge (both TDV, Pomerode, SC, Brazil). The wedge was positioned to promote gingival tissue separation and ensure adequate adaptation of the matrix at the cervical level, thereby allowing proper containment of the restorative material and minimizing excess resin in the gingival region. This procedure was not necessary for Class I cavities.

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SELECTIVE ACID ETCHING

After placement of the matrix and wedge, selective enamel etching was performed with 37% phosphoric acid (Condac, FGM, Joinville, SC, Brazil) for 30 seconds, followed by a 30-second water rinse. The cavity was gently dried while maintaining dentin moisture.

APPLICATION OF THE ADHESIVE SYSTEM

The universal adhesive BeautiBond Xtreme (Shofu, Kyoto, Japan) was applied to the cavity surfaces for 20 seconds. Solvent evaporation was performed using a gentle air stream for 10 seconds at an approximate distance of 10 cm. The adhesive system was then light-cured for 20 seconds.

ALLOCATION OF TEETH TO THE GROUPS

Allocation of the restorative technique was not randomized. The technique for each tooth was assigned by the principal investigator after clinical and radiographic examination. Because all included cavities were deep (extending to the inner third of the dentin), the decision was based on cavity extent: more extensive cavities were preferentially restored with the bulk-fill technique, which allows placement of increments of up to 4 mm, whereas less extensive cavities were restored with the conventional incremental technique.

RESTORATIVE TECHNIQUE: CONVENTIONAL GROUP (CG)

In the CG, restorations were placed using the nanohybrid resin composite Beautifil II LS (Shofu, Kyoto, Japan) with the incremental technique. Oblique increments of up to 2 mm were individually light-cured for 40 seconds before placement of the subsequent increment.

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RESTORATIVE TECHNIQUE: BULK-FILL GROUP (BG)

In the BG, restorations were placed using Beautifil Bulk Restorative (Shofu, Kyoto, Japan) in a single increment of up to 4 mm, followed by a 2-mm superficial layer of Beautifil II LS. Both the bulk-fill increment and the superficial covering layer were light-cured for 40 seconds.

LIGHT CURING

Light-curing procedures were performed using an LED curing unit (Gnatus Equipamentos Odontológicos, Ribeirão Preto, São Paulo, Brazil) with an emission spectrum of 440–480 nm and an irradiance of approximately 1200 mW/cm². Before the study began, all curing units were evaluated by a qualified technician to confirm adequate irradiance. A prolonged light-curing protocol was adopted to ensure adequate polymerization in deep cavities, taking into account the irradiance characteristics of the curing unit and the depth of the restorations.

FINISHING AND POLISHING

Finishing and polishing were performed using fine and extra-fine diamond burs (KG Sorensen, Cotia, São Paulo, Brazil), followed by abrasive silicone cups (Microdont, São Paulo, Brazil). A silicon carbide brush (TDV, Pomerode, SC, Brazil) and Diamond Excel polishing paste (FGM, Joinville, SC, Brazil) were then used with a felt disc according to the manufacturers' instructions.

CLINICAL EVALUATION

All restorations were clinically re-evaluated after 12 months according to the 2007 FDI clinical criteria[9,13], considering the esthetic, functional, and biological parameters[5,23,26].

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Evaluations were performed by four calibrated examiners. Twelve criteria were evaluated: four esthetic (surface luster; staining; color match and translucency; and esthetic anatomical form), four functional (fracture of material and retention; marginal adaptation; occlusal contour and wear; and approximal contact point), and four biological (postoperative hypersensitivity and tooth vitality; recurrence of caries, erosion, and abfraction; tooth integrity; and periodontal response). Each criterion was scored from 1 (clinically excellent) to 5 (clinically poor); scores 1 to 3 were considered clinically acceptable, score 4 was considered clinically unsatisfactory but repairable, and score 5 indicated that replacement was required. The criteria and their respective scores are presented in Table 2.

Table 2. FDI (2007) clinical criteria for the evaluation of direct restorations

Criterion	1 Clinically excellent / very good	2 Clinically good	3 Clinically sufficient / satisfactory	4 Clinically unsatisfactory (repairable)	5 Clinically poor (replacement required)
Esthetic					
Surface luster	Gloss comparable to enamel	Slightly dull, imperceptible at conversational distance	Dull surface but acceptable; covered by a saliva film	Rough surface, not covered by a saliva film; not correctable by simple polishing	Very rough surface with unacceptable plaque retention
Staining (surface and margin)	No surface or marginal staining	Minor surface or marginal stains, easily removed by polishing	Moderate surface or marginal staining, not esthetically unacceptable	Unacceptable staining; major intervention required	Severe, generalized, or deep staining inaccessible to intervention
Color match and translucency	Good color match; no difference in shade or translucency	Minor deviations in shade or translucency	Distinct deviation, but acceptable and not affecting esthetics	Localized, clinically relevant deviation correctable by repair	Unacceptable deviation; replacement required
Esthetic anatomical form	Ideal form	Form slightly deviates from normal	Form differs from normal but is esthetically acceptable	Form esthetically unacceptable; correction required	Form unsatisfactory or lost; replacement required
Functional					
Fracture of material and retention	No fractures or cracks	Small hairline crack	Two or more fine fissures or small fractures that do not affect integrity	Chipping fractures affecting proximal contacts or marginal quality	Partial or complete loss of the restoration
Marginal adaptation	Harmonious contour, without defects, white lines, or discoloration	Marginal gap (<150 µm); small marginal fracture removable by polishing	Marginal gap (<250 µm), not removable; small marginal fractures	Marginal gap (>250 µm) or exposed dentin; severe marginal irregularities	Restoration loose or partially/completely dislodged
Occlusal contour and wear	Physiological wear equivalent to that of enamel	Wear slightly different from that of enamel	Wear different from that of enamel but within biological variation	Wear considerably exceeding that of enamel; loss of occlusal contacts	Wear substantially and excessively exceeding that of enamel
Approximal contact point	Normal contact point (floss or 25-µm metal blade can pass)	Contact slightly too strong, without disadvantage	Somewhat weak contact, without damage to tooth, gingiva, or periodontium (50-µm blade can pass)	Too weak contact, with possible damage due to food impaction (100-µm blade can pass)	Too weak contact and/or clear damage due to food impaction, pain, or gingivitis
Biological					

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Criterion	1 Clinically excellent / very good	2 Clinically good	3 Clinically sufficient / satisfactory	4 Clinically unsatisfactory (repairable)	5 Clinically poor (replacement required)
Postoperative hypersensitivity and tooth vitality	No hypersensitivity; normal vitality	Mild hypersensitivity for a limited period	Moderate hypersensitivity: mild symptoms without need for treatment	Intense hypersensitivity; persistent mild symptoms	Acute pulpitis or nonvital tooth; endodontic treatment required
Recurrence of caries, erosion, and abfraction	Absence of primary or secondary caries	Small, localized demineralization	Large areas of demineralization without dentin exposure	Cavitated caries, accessible and repairable	Deep caries not accessible for repair
Tooth integrity (enamel cracks, tooth fractures)	Complete integrity	Minor marginal enamel fractures (<150 μm); fine enamel fissure (<150 μm)	Marginal enamel defect (<250 μm)	Large marginal enamel defects (>250 μm) or exposed base	Extensive fractures with partial or complete loss of the restoration
Periodontal response	No plaque accumulation, inflammation, or pockets	Little plaque accumulation; no inflammation or pocket development	Difference of up to one grade in papilla bleeding index compared with control teeth	Difference of more than one grade in papilla bleeding index or pocket depth increase >1 mm; intervention required	Severe or acute gingivitis or periodontitis

Source: Adapted from the FDI clinical criteria (2007)[9,10].

In cases of disagreement among the evaluators, the final score was established by consensus under the supervision of the principal investigator.

EXAMINER CALIBRATION

Inter-examiner calibration was performed by the principal investigator using kappa statistics before the clinical evaluation phase. The kappa coefficient obtained ($\kappa = 0.81$) indicated excellent inter-examiner agreement according to the FDI clinical criteria[7,13].

STATISTICAL ANALYSIS

Statistical analyses were performed using R software (R Core Team, Vienna, Austria). Because FDI scores are ordinal data, comparisons between the conventional incremental and bulk-fill restorative techniques were performed using the two-tailed paired Wilcoxon signed-rank test. The patient was considered the unit of analysis. When a patient received more than one restoration with the same technique, the median score of these restorations was calculated for each criterion, so that each patient contributed one paired observation per technique. This approach accounts for the dependence among restorations placed in the same patient; however,

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it does not use all restoration-level information and gives equal weight to patients with different numbers of restorations. Because patient-level medians were used, and the median of an even number of observations corresponds to the mean of the two central values, some summary values are not integers (e.g., 1.25). Scores were summarized at the patient level as medians, interquartile ranges (IQR), and minimum–maximum values, and at the restoration level as absolute and relative frequencies of each score. Statistical significance was set at 5% ($\alpha = 0.05$).

USE OF ARTIFICIAL INTELLIGENCE

During the preparation of this manuscript, the authors used Claude (Anthropic) to assist with English-language editing. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

RESULT

A total of 31 restorations in deep cavities of posterior teeth, classified as Black's Class I and II, were evaluated in 13 patients (Table 3). Ten patients, who received restorations placed using both restorative techniques (27 restorations; CG, n = 14; BG, n = 13), were included in the intraindividual comparison between the evaluated approaches. Among the restored cavities, 80.6% (n = 25) were Class II and 19.4% (n = 6) were Class I, with a predominance of occluso-distal (OD) and mesio-occlusal (MO) cavity preparations. Complex cavities (three or more surfaces) were more frequent in the BG (35.3%) than in the CG (7.1%), consistent with the allocation criterion. The descriptive characteristics of the restorations, including the tooth distribution, restored surfaces, and Black's cavity classification, are presented in Table 3.

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Table 3. Distribution of deep restorations according to restorative technique (n = 13 patients; 31 restorations)

Variable	Category	Technique		Total (n = 31)
		CG (n = 14)	BG (n = 17)	
		Frequency, *n* (%)		
Tooth	14	0 (0.0%)	1 (5.9%)	1 (3.2%)
	15	2 (14.3%)	0 (0.0%)	2 (6.4%)
	16	1 (7.1%)	1 (5.9%)	2 (6.4%)
	17	2 (14.3%)	2 (11.8%)	4 (12.9%)
	24	0 (0.0%)	1 (5.9%)	1 (3.2%)
	25	2 (14.3%)	0 (0.0%)	2 (6.4%)
	27	1 (7.1%)	1 (5.9%)	2 (6.4%)
	34	1 (7.1%)	2 (11.8%)	3 (9.7%)
	35	1 (7.1%)	0 (0.0%)	1 (3.2%)
	36	1 (7.1%)	1 (5.9%)	2 (6.4%)
	37	0 (0.0%)	5 (29.4%)	5 (16.1%)
	44	1 (7.1%)	0 (0.0%)	1 (3.2%)
	45	0 (0.0%)	2 (11.8%)	2 (6.4%)
	46	1 (7.1%)	1 (5.9%)	2 (6.4%)
	48	1 (7.1%)	0 (0.0%)	1 (3.2%)
Number of restored surfaces	Complex (≥ 3 surfaces)	1 (7.1%)	6 (35.3%)	7 (22.6%)
	Multi-surface	9 (64.3%)	11 (64.7%)	20 (64.5%)
	Single-surface	4 (28.6%)	0 (0.0%)	4 (12.9%)
Surface	D	1 (7.1%)	0 (0.0%)	1 (3.2%)
	MO	3 (21.4%)	4 (23.5%)	7 (22.6%)
	MOD	1 (7.1%)	3 (17.6%)	4 (12.9%)
	MODL	0 (0.0%)	1 (5.9%)	1 (3.2%)
	O	3 (21.4%)	0 (0.0%)	3 (9.7%)
	OD	5 (35.7%)	3 (17.6%)	8 (25.8%)
	ODV	0 (0.0%)	2 (11.8%)	2 (6.4%)
	OM	1 (7.1%)	3 (17.6%)	4 (12.9%)
	OV	0 (0.0%)	1 (5.9%)	1 (3.2%)
Black's Class	I	4 (28.6%)	2 (11.8%)	6 (19.4%)
	II	10 (71.4%)	15 (88.2%)	25 (80.6%)

CG: Conventional Group; **BG:** Bulk-Fill Group.
FDI tooth numbering system was used.
D: distal; **M:** mesial; **O:** occlusal; **V:** vestibular; **L:** lingual.

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After 12 months of clinical follow-up, no statistically significant differences were detected between the conventional incremental and bulk-fill restorative techniques for any of the esthetic, functional, or biological FDI criteria evaluated ($p > 0.05$; Table 4). For occlusal contour and wear; recurrence of caries, erosion, and abfraction; and postoperative hypersensitivity and tooth vitality, the test could not be computed because all paired differences were zero.

Table 4. Distribution of FDI scores (restoration level) and comparison between restorative techniques (patient level) in deep cavities after 12 months (n = 10 patients; 27 restorations)

Criterion	Group	FDI score, n (%)					Median (IQR)[b]	Min–max[b]	*p*-value
		1	2	3	4	5			
Esthetic									
Surface luster	CG	9 (64.3)	4 (28.6)	0 (0.0)	1 (7.1)	0 (0.0)	1.00 (1.00–2.00)	1.00–4.00	0.4185
	BG	3 (23.1)	7 (53.8)	3 (23.1)	0 (0.0)	0 (0.0)	2.00 (1.00–2.00)	1.00–3.00	
Staining (surface and margin)	CG	9 (64.3)	3 (21.4)	1 (7.1)	1 (7.1)	0 (0.0)	1.00 (1.00–2.00)	1.00–4.00	0.8339
	BG	4 (30.8)	4 (30.8)	5 (38.5)	0 (0.0)	0 (0.0)	2.00 (1.00–3.00)	1.00–3.00	
Color match and translucency	CG	8 (57.1)	4 (28.6)	1 (7.1)	1 (7.1)	0 (0.0)	1.25 (1.00–2.00)	1.00–4.00	0.2604
	BG	2 (15.4)	7 (53.8)	4 (30.8)	0 (0.0)	0 (0.0)	2.00 (2.00–3.00)	1.00–3.00	
Esthetic anatomical form	CG	8 (57.1)	4 (28.6)	1 (7.1)	1 (7.1)	0 (0.0)	1.50 (1.00–2.00)	1.00–4.00	0.4185
	BG	3 (23.1)	7 (53.8)	3 (23.1)	0 (0.0)	0 (0.0)	2.00 (2.00–3.00)	1.00–3.00	
Functional									
Fracture of material and retention	CG	13 (92.9)	1 (7.1)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–2.00	0.3173
	BG	12 (92.3)	1 (7.7)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–1.50	
Marginal adaptation	CG	9 (64.3)	4 (28.6)	1 (7.1)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–3.00	0.2249
	BG	7 (53.8)	4 (30.8)	2 (15.4)	0 (0.0)	0 (0.0)	1.25 (1.00–2.00)	1.00–3.00	
Occlusal contour and wear	CG	12 (85.7)	2 (14.3)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–2.00	—
	BG	10 (76.9)	3 (23.1)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–2.00	
Approximal contact point[a]	CG	11 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–1.00	0.0679
	BG	7 (53.8)	5 (38.5)	1 (7.7)	0 (0.0)	0 (0.0)	1.25 (1.00–2.00)	1.00–3.00	
Biological									
Postoperative hypersensitivity and tooth vitality	CG	14 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–1.00	—
	BG	13 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–1.00	
Recurrence of caries, erosion, and abfraction	CG	13 (92.9)	1 (7.1)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–1.00	—
	BG	13 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–1.00	
Tooth integrity	CG	12 (85.7)	1 (7.1)	1 (7.1)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–3.00	0.1797
	BG	13 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–1.00	
Periodontal response[a]	CG	11 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–1.00)	1.00–1.00	0.1797
	BG	9 (69.2)	4 (30.8)	0 (0.0)	0 (0.0)	0 (0.0)	1.00 (1.00–2.00)	1.00–2.00	

FDI criteria: score 1 = clinically excellent/very good; score 5 = clinically poor (replacement required). Score distributions are presented as the number (%) of restorations. [a]Not evaluated in Class I occlusal restorations (CG, n = 11; BG, n = 13). [b]Median (interquartile range, IQR) and minimum–maximum values calculated from patient-level median scores (n = 10 patients). **Statistical test:** two-tailed paired Wilcoxon signed-rank test ($\alpha = 0.05$); —, test not computed because all paired differences were zero. **CG:** Conventional Group; **BG:** Bulk-Fill Group.

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No restoration received a score of 5, and no restoration required replacement during the 12-month follow-up period. A score of 4 was recorded in one restoration of the CG (Class I, occlusal) for surface luster, staining, color match and translucency, and esthetic anatomical form; this restoration was repolished at the recall visit, and no further intervention was required. All other restorations received scores of 1 to 3 (clinically acceptable) for all criteria. No caries lesions requiring treatment, postoperative hypersensitivity, loss of tooth vitality, or endodontic complications were observed.

DISCUSSION

In this preliminary split-mouth clinical study, no statistically significant differences were detected between the conventional incremental and bulk-fill restorative techniques in deep posterior cavities after 12 months for any of the esthetic, functional, or biological parameters evaluated according to the FDI clinical criteria[27–29]. Furthermore, no restoration required replacement, and no recurrent caries requiring treatment, postoperative sensitivity, or endodontic complications were observed during the follow-up period. Therefore, the null hypothesis was not rejected. These short-term findings are in line with previous studies reporting clinically acceptable outcomes for both techniques when appropriate adhesive and restorative procedures are followed[3–5,18-20,23]. However, the absence of statistically significant differences should not be interpreted as evidence of equivalence, because the study was not designed to test equivalence or non-inferiority.

Conventional incremental resin composite restorations have consistently demonstrated favorable long-term outcomes because incremental placement reduces polymerization shrinkage stress and improves control of the cavity configuration factor (C-factor), particularly in deep posterior cavities[3,5–7]. Bulk-fill resin composites were developed to simplify restorative procedures by allowing the placement of thicker increments while maintaining an adequate

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depth of cure[3,4,16,28]. In the present study, no statistically significant differences were detected between the techniques regarding marginal adaptation, anatomical form, proximal contact, and biological response after 12 months. These findings are consistent with previous randomized clinical studies reporting similar short-term outcomes for bulk-fill and conventional incremental restorative techniques in posterior teeth[4,5,19,27,29,30].

Both restorative approaches used materials based on Giomer technology containing surface pre-reacted glass-ionomer (S-PRG) fillers[16], and no control group with a different composition was included. Consequently, the present comparison addresses the restorative technique (bulk-fill versus incremental) rather than the bioactive composition of the materials, and the results cannot be attributed to a specific clinical effect of S-PRG bioactivity. Previous experimental studies have shown that S-PRG fillers release fluoride and other ions, exhibit acid-buffering capacity, and may contribute to a favorable biological environment surrounding restorations[16,21]. However, this clinical study was not designed to directly evaluate ion release, remineralization, or other biological mechanisms associated with these materials. Therefore, the absence of secondary caries, marginal degradation, and biological complications should be interpreted as favorable short-term clinical outcomes rather than as evidence of the bioactive effects of the restorative materials.

The favorable marginal integrity observed in both groups may also be attributed to the adhesive protocol adopted in this study[16,18,27,29]. Selective enamel etching likely enhanced micromechanical retention and bond stability, thereby reducing the risk of marginal leakage and restoration failure[17,24,28,29]. Previous studies have shown that the adhesive strategy and clinical technique are major determinants of the longevity and marginal stability of direct restorations, regardless of the restorative material used[16,27]. Accordingly, the absence of secondary caries and biological complications observed in the present study may be attributed not only to the restorative materials but also to the standardized clinical protocol, including the

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use of an S-PRG-based adhesive (BeautiBond Xtreme) together with S-PRG-based restorative materials throughout the restorative procedure[5,18,21,27–29]. Nevertheless, because this study was not designed to isolate the contribution of the adhesive system, its individual effect cannot be determined.

From a functional standpoint, none of the restorations exhibited bulk fractures, loss of retention, excessive wear, or clinically relevant occlusal failure throughout the 12-month follow-up period. These findings suggest that both techniques provided adequate mechanical stability in deep posterior cavities in the short term, in agreement with previous clinical studies evaluating bulk-fill and conventional incremental resin composites[18,19,20,23,28–30].

However, previous studies have warned that inadequate light curing in deep cavities may compromise polymerization of bulk-fill restorative materials, thereby increasing the risk of marginal degradation and restoration failure over time[12,21,28]. In the present study, this potential limitation was minimized by using a high-intensity LED curing unit with an extended exposure time of 40 seconds per increment to optimize light transmission and polymerization of the resin composite, even in deep cavity preparations. Although the degree of conversion was not directly evaluated, the absence of postoperative sensitivity, pulpal complications, and early clinical failures is consistent with adequate short-term performance of the restorative and light-curing protocols adopted in this study[15,17,23,26,28–30].

Regarding the esthetic outcomes, no statistically significant differences were detected between the techniques for color match, surface luster, and surface texture after 12 months of clinical follow-up. This may be explained, at least in part, by the use of the same nanohybrid Giomer resin composite (Beautifil II LS) as the outer restorative layer in both groups, thereby providing greater optical uniformity. Furthermore, previous clinical studies have demonstrated that finishing and polishing procedures may exert a greater influence on the long-term esthetic performance of direct restorations than the restorative technique itself[5,18,21]. One restoration in

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the CG received a score of 4 for esthetic criteria and was repolished at the recall visit. Because all restorations were placed by undergraduate students, this finding is probably related to operator-dependent finishing and polishing procedures rather than to the restorative technique, and it should not be considered representative of the overall performance of either group.

The biological outcomes were likewise favorable. No gingival inflammation, bleeding on probing, marginal discoloration associated with secondary caries, or periodontal complications were observed throughout the 12-month follow-up period. Previous clinical studies have identified operative technique, matrix adaptation, finishing and polishing procedures, and adhesive protocol standardization as key determinants of the longevity and biological stability of direct restorations[6,10,14,20,21,27–29].

All restorative procedures were performed by calibrated undergraduate dental students under the direct supervision of the same experienced faculty member. Although operator variability is inherent in educational environments, prior student calibration and continuous supervision by the same faculty member were intended to standardize the restorative and adhesive procedures and to minimize technique-related variability among operators[3,28,29]. Consequently, these findings may be relevant mainly to supervised teaching settings.

The present study has several limitations that should be acknowledged. First, the sample was small, and no a priori sample size calculation was performed; therefore, the study may have lacked statistical power to detect clinically relevant differences, and its findings should be regarded as preliminary. Second, allocation of the restorative technique was not randomized but was based on cavity extent, as determined by the principal investigator. Consequently, more extensive cavities were preferentially assigned to the BG, which resulted in an imbalance in cavity complexity between the groups (complex cavities: 35.3% in the BG vs. 7.1% in the CG). This allocation strategy represents a potential source of selection bias (confounding by indication) and may have influenced the comparison between the techniques; the direction and

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magnitude of this effect cannot be determined from the present data. Third, because some patients received more than one restoration with the same technique, patient-level median scores were used in the paired analysis; this approach accounts for the dependence among restorations placed in the same patient but reduces the information available and does not account for differences in the number of restorations per patient. Finally, the 12-month follow-up reflects only short-term clinical performance, and longer follow-up is required before conclusions can be drawn regarding long-term behavior. Nevertheless, the split-mouth design reduced interindividual biological variability by allowing participants to serve as their own controls.

Longer-term randomized clinical studies with larger samples, preferably designed to assess equivalence or non-inferiority, are warranted to confirm these findings and to evaluate the long-term clinical performance of S-PRG-based restorative systems.

CONCLUSION

Within the limitations of this preliminary split-mouth clinical study, no statistically significant differences were detected between the conventional incremental and bulk-fill restorative techniques in deep posterior cavities after 12 months regarding the esthetic, functional, or biological parameters evaluated according to the FDI clinical criteria. Because the study was not designed to test equivalence and the follow-up was short, these findings should be interpreted with caution, and longer-term randomized clinical studies with larger samples are needed.

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AUTHORS' CONTRIBUTIONS

Walter Leonardo Siqueira Zaia: Conceptualization; Methodology; Investigation; Data curation; Formal analysis; Writing – original draft; Writing – review & editing; Supervision. Flávia Lucisano Botelho do Amaral: Methodology; Supervision; Writing – review & editing; Validation.

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interest related to this study.

DATA AVAILABILITY

The datasets generated and analyzed during the current study are not publicly available owing to ethical restrictions related to patient confidentiality but are available from the corresponding author upon reasonable request.

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