ORIGINAL ARTICLE

Sixty-month follow up of three different universal adhesives used with a highly-filled flowable resin composite in the restoration of non-carious cervical lesion

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Abstract

Objective The purpose of this clinical trial was to evaluate and compare the performances of three different universal adhesives used with a highly filled flowable universal resin composite in the restoration of non-carious cervical lesions (NCCLs) over a 60-month period.

Material and methods Ninety-nine NCCLs were restored at 18 participants. NCCLs were divided into three different universal adhesive groups: Clearfil Universal Bond (CU) ($n = 31$), iBOND Universal (IU) ($n = 33$), and G-Premio Bond (GP) ($n = 35$). Prior to the adhesive procedures, selective enamel etching was performed with 37% phosphoric acid in all experimental groups. Adhesive systems were applied following the manufacturers' instructions, and the lesions were restored with a highly filled flowable resin composite (G-ænial Universal Flo). Restorations were finished and polished immediately after placement. All restorations were scored with regard to retention, marginal discoloration, marginal adaptation, sensitivity, surface texture, and color match using modified United States Public Health Service (USPHS) criteria after 1 week (baseline) and 6, 12, 18, 24, 36, and 60 months. Statistical analyses were performed using chi-square and McNemar's and Kaplan Meier tests. The level of significance was set at $p < 0.05$.

Results After 60 months, the recall rate was 72.2%. Survival rates of CU, IU, and GP restorations were 87%, 85.2%, and 96.5%, respectively. Five CU (25%), 8 IU (34.8%), and 12 GP (42.9%) restorations exhibit bravo scores for marginal adaptation. However, no differences were seen among them. CU showed lower bravo score than IU and GP for marginal discoloration (CU, 0%; IU, 26.1%; GP, 32.1%). Two CU, 7 IU, and 6 GP restorations showed bravo scores for surface texture, and 2 (9.1%) CU and 1 (3.3%) GP restorations were scored as bravo score for color match ($p > 0.05$).

Conclusion The tested universal adhesives showed similar success rates during the 60-month follow-up. However, CU showed better clinical performance than IU and GP in terms of marginal adaptation and discoloration.

Trial registration ClinicalTrials.gov Identifier: NCT03415412

Clinical relevance The long-term clinical performances of the three universal adhesives in the restoration of NCCLs using selective enamel etching mode were successful after 60 months.

Keywords Non-carious cervical lesion · Selective enamel etching · Universal adhesive

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Introduction

Non-carious cervical lesions (NCCLs) predominantly affect the elderly population and frequently necessitate restorative treatments due to discomfort caused by the loss of dental structure. The high prevalence of NCCLs in elderly patients is consistent with the gingival recession that occurs with age, and wear in the cervical area is important [1]. NCCLs occur due to multiple factors, including erosion, abrasion, and abfraction; these lesions extend deeper if they are not treated appropriately [2]. Although the underlying causes

of NCCLs vary, they all cause tooth wear through various mechanisms. NCCLs may lead to dentin hypersensitivity due to exposure of the dentin to the oral environment [2], which indicates the importance of treating these lesions for patient comfort.

One of the challenges of NCCL restoration is the difficulty in controlling moisture at the cervical margins [3]. The restorations are placed near the margins or, in some cases, at the subgingival areas. These restorations should be isolated from the gingival crevicular fluid to ensure the longevity of NCCLs. Biomechanical loadings at cervical areas may result in flexure and restoration failure; therefore, many clinicians prefer flowable resin composites with 20–30% lower elastic modulus than hybrid resin composites [4, 5]. Reduced elastic modulus can attenuate the stresses on the teeth generated during mechanical loading [6]. In addition, the use of flowable resin composites produces quicker results than other resin composites, since time is not spent on shaping the restoration [6].

The etch-and-rinse technique is useful for adhesion to both enamel and dentin; this technique relies on the initial application of phosphoric acid to enamel and dentin. The etch-and-rinse technique can be applied via both two- and three-step etch-and-rinse adhesives (using one bottle and separate bottles of primer and adhesive, respectively) [7]. In comparison, self-etch adhesive systems, which do not include phosphoric acid pretreatment of dentin and enamel, can be applied using one- or two-step methods. Previous studies have shown that these adhesives are reliable and effective for retention [8–10].

Universal adhesives can be applied using three techniques: etch-and-rinse, self-etch, and selective enamel etching. Enamel pretreatment is recommended to increase the stability of bonding interfaces [8]. Some universal adhesives contain functional monomers, such as 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP), which enhance bonding through chemical adhesion to the tooth [11]. In addition, the pH of universal adhesives may be directly related to the binding ability of the material, which may cause inadequate enamel bonding [12].

Phosphoric acid pretreatment of enamel increases surface wettability, roughness, and free energy, which improves bonding despite reduced surface hardness of enamel [13–15]. Acid etching on dentin removes mineral crystals and exposes the collagen fibrils [16]. However, demineralized dentin is hydrophobic and leads to osmosis of water from dentin. This leads to the formation of osmotic blisters, which reduce the bond strength. The application of phosphoric acid to the dentin activates endogenous collagenolytic proteases and leads to the degradation of the interface between the adhesive and dentin [8]. In addition, the dentin collagen is susceptible to degradation by matrix metalloproteinases, resulting in failure of the adhesive interface

due to fatigue [8]. Degradation of the resin–dentin interface can reduce the longevity of restorations [7]. However, the enamel margins of cavities do not undergo degradation; therefore, the enamel bonding is important for adhesion to dental structures. Previous studies have shown that universal adhesives do not undergo degradation on dentin after the aging process when the etch-and-rinse mode is used [17, 18]. For patients at low risk of caries, degradation at the dentin–resin interface may be disregarded [19].

In vitro studies have demonstrated that enamel bonding provided by self-etch adhesives is inferior to that provided by etch-and-rinse systems [20–22]. In addition, a meta-analysis found that phosphoric acid etching of enamel increases the bond strength to the substrate of universal adhesives [23]. Some clinical studies have reported that the etch-and-rinse approach leads to increased retention rates and reduced marginal discoloration [24, 25]. However, other clinical trials reported that the clinical performance of universal adhesives at 18–36 months was not influenced by the application mode [26–28].

Many in vitro studies have reported advantages of selective enamel etching, including increased bond strength of self-etch adhesive systems to the enamel after etching [29–32]. In addition, selective enamel etching before the application of universal adhesives improved the performance of the adhesives [33–35]. No previous study has compared universal adhesives with different ingredients when applying the selective enamel etching mode to NCCLs in combination with a highly filled flowable resin composite. In addition, most previous studies of universal adhesives followed the restorations for 1–3 years [6].

Therefore, the aim of this randomized clinical trial was to compare the clinical performance of three universal adhesives (Clearfil Universal Bond, iBOND Universal, and G-Premio Bond) applied to NCCLs using a universal flowable resin composite (G-ænial Universal Flo) in selective enamel etching mode. The outcomes were compared after 60 months. The null hypothesis stated that the clinical performance of the three universal adhesive systems placed with a flowable universal resin composite would not be significantly different.

Materials and methods

The experimental design was in accordance with the Consolidated Standards of Reporting Trials (CONSORT) statement.

Ethics approval

This clinical trial was approved by the Institutional Research Ethics Committee. Participants were informed about the

study objectives and content. Written consent was obtained from all participants.

Protocol registration

The study was registered at ClinicalTrials.gov.

Trial design and setting

This was a randomized, double-blind, controlled clinical trial. The study was performed at the Restorative Dentistry Department.

Sample size calculation

G* Power statistical software was used to calculate the sample size. For an effect size difference of 0.40 between the groups with 80% power and an alpha error of 5%, at least 26 restorations were needed in each group. Considering the possibility of dropouts during follow-up, the sample size was increased to at least 31 in each group, and a total of 99 restorations were performed.

Patient selection

Based on the inclusion and exclusion criteria, we selected patients presenting to the Department of Restorative Dentistry for routine dental care (Table 1). The cervico-incisal or cervico-occlusal height of the lesions was measured using a periodontal probe (32 lesions 1.5–2.5 mm in size and 67 lesions > 2.5–4.0 mm in size). Non-retentive lesions with a cavosurface margin involving a maximum of 50% of the enamel were included. One clinician performed the assessments using an explorer, mouth mirror, and periodontal probe.

Randomization

Each patient received at least three restorations, and the adhesive systems were randomized using computer-generated tables. A number was assigned to each adhesive in the tables (only the clinician not involved in the study could see the tables) for patient allocation.

Restorative procedures

Ninety-nine restorations were performed on 18 patients (7 males, 11 females) with a mean age of 47 years. Patients were provided with oral hygiene instructions preoperatively and received dental prophylaxis for 1 week preoperatively. All lesions were restored by the same clinician, who did not participate in the selection of study participants. Teeth were cleaned using a rotating rubber cup in a slow-speed handpiece and pumice; the teeth were washed and dried, but not desiccated, before restoration. Adhesives and a highly filled flowable universal resin composite material (G-ænial Universal Flo; GC, Tokyo, Japan) were applied according to the manufacturers' recommendations (Table 2). The adhesive groups were CU (Clearfil Universal Bond; Kuraray Dental, Tokyo, Japan) ($n=31$), IU (iBOND Universal; Heraeus Kulzer GmbH, Hanau, Germany) ($n=33$), and GP (G-Premio Bond; GC) ($n=35$).

Each increment of the highly filled flowable resin composite (G-ænial Universal Flo) was light-cured for 40 s (Radii Plus; SDI, Bayswater, Australia). The LED light-curing unit was set at 1,200 mW/cm^2. The restorations were contoured using flame-shaped fine finishing diamond burs (Diatech; Charleston, SC, USA) in a slow-speed handpiece under water spray; then, the restorations were polished using aluminum oxide discs (Optidisc; Kerr, Orange, CA, USA).

Clinical assessments

Patients were followed up at 1 week (baseline) and 6, 12, 18, 24, 36, and 60 months after placement. Forty-eight-month evaluations could not be performed due to restrictions related to the COVID-19 pandemic. The restorations were checked for retention, marginal adaptation, marginal discoloration, surface texture, color match, and post-operative sensitivity, according to the US Public Health Service (USPHS) criteria.

The restorations were evaluated by two experienced examiners who were blinded to the group assignments and

Table 1 Inclusion and exclusion criteria for participants

Inclusion criteria	Exclusion criteria
(a) Being at least 18 years old	(a) Severe periodontal disease; rampant, uncontrolled caries; xerostomia
(b) Having at least 20 teeth under occlusion	(b) Serious medical problems preventing them from attending review visits
(c) Having at least three NCCLs that needed restoration in different teeth and that were similar in size (depth), ranging from 1 to 3 mm	(c) Poor gingival health
	(d) Heavy bruxism
	(e) Removable partial dentures
	(f) Undergoing bleaching treatment or orthodontic treatment
	(g) Patients with severe hypersensitivity (checked with a cold test)

Table 2 Materials used in the study

Material/manufacturer	Batch No	Composition	Application
Clearfil Universal Bond/Kuraray Dental, Tokyo, Japan	4T0015	MDP Bis-GMA HEMA Hydrophilic aliphatic dimethacrylate Colloidal silica Silane coupling agent dl-Camphorquinone Ethanol Water	Selective etch technique Apply phosphoric acid etching gel (37%) to the enamel, leave it in place for 30 s, and then rinse and dry Apply bond to the entire lesion with the applicator brush and rub for 10 s Dry the entire lesion sufficiently by blowing mild air for more than 5 s until bond does not move Light-cure bond with 1200 mW/cm^2 LED for 10 s
iBOND Universal/Heraeus Kulzer, Hanau, Germany	010021	Acetone 4-methacryoxyethltrimellitic acid anhydride Diurethane dimethacrylate	Selective etch technique Apply phosphoric acid etching gel (37%) to enamel and leave it in place for 30 s, and then rinse and dry Apply bond to the entire lesion with the applicator brush and rub for 20 s Dry the entire lesion sufficiently by blowing mild air for more than 5 s until bond does not move Light-cure bond with 1200 mW/cm^2 LED for 10 s
G-Premio Bond/GC, Tokyo, Japan	160413A	MDP Acetone Dimethacrylate Phosphoric acid ester monomer Photoinitiator BHT MDTP	Selective etch technique Apply phosphoric acid etching gel (37%) to enamel and leave it in place for 30 s and then rinse and dry Apply bond to the lesion with the applicator brush Leave undisturbed for 10 s Dry thoroughly for 5 s under maximum air pressure Light-cure bond with 1200 mW/cm^2 LED for 10 s
G-ænial Universal Flo/GC, Tokyo, Japan	1208012	UDMA Bis-MEPP TEGDMA Silicon dioxide (16 nm) Strontium glass (200 nm) Pigment Photo initiator	Place the dispensing tip as close as possible to the lesion and slowly push the plunger to syringe material Light-cure for 20 s (LED) (1200 mW/cm^2)

UDMA, urethane dimethacrylate; *MDP*, 10-methacryloyloxydecyl dihydrogen phosphate; *Bis-GMA*, bisphenol A diglycidyl methacrylate; *HEMA*, 2-hydroxyethyl methacrylate; *BHT*, butylated hydroxytoluene; *MDTP*, methacryloyloxydecyl dihydrogen thiophosphate

not involved in the placement of restorations. The calibration involved reviewing 10 representative photographs for each criterion. Then, the examiners evaluated 10–15 restorations during two appointments. Intra- and inter-examiner agreement of at least 85% was necessary to begin the evaluation. Participants were also blinded to the group assignments.

Statistical analyses were performed using SPSS software (version 22.0; IBM Corp., Armonk, NY, USA). Pearson chi-square tests were used to compare the universal adhesives at each recall. Differences in the ratings of the three materials were assessed at 6, 12, 18, 24, 36, and 60 months. Changes across time for each adhesive material were analyzed using Cochran's Q test. McNemar's test was used to compare the materials in terms of marginal adaptation and discoloration and the surface texture scores of each adhesive with baseline scores across time points. Kaplan–Meier analysis was performed to compare the survival rates of the restorations. The level of significance was set at $p < 0.05$.

Results

Figure 1 is a flow chart of the study participants. The recall rates at the 6-, 12-, 18-, 24-, 36-, and 60-month evaluations were 100%, 88.8%, 88.8%, 88.8%, 77.7%, and 72.2%, respectively. Table 3 presents the clinical outcomes of the tested adhesives.

Only 1 (3.2%) IU restoration lost retention at the 18-month recall. No retention loss was observed at the 24-month recall. Two (8.3%) CU and 1 (3.7%) IU restorations lost retention at the 36-month evaluation. At the 60-month recall, 1 (4.8%) CU, 2 (8.0%) IU, and 1 GP (3.4) restorations lost retention.

Four (18.2%) CU, eight (30.8%) IU, and ten (33.3%) GP restorations showed bravo scores for marginal adaptation after 36 months. However, no significant differences were detected among the groups ($p = 0.457$). At the 60-month evaluation, 5 (25%) CU, 8 (34.8%) IU, and 12 (42.9%) GP restorations were scored as bravo, with no significant differences among the groups ($p = 0.442$). McNemar's test showed significant changes in marginal adaptation in IU and GP after 24 ($p = 0.008$ and $p = 0.002$, respectively), 36 ($p = 0.008$ and $p = 0.001$, respectively), and 60 ($p = 0.001$ for both) months.

Six (23.1%) IU and six (20.0%) GP restorations showed bravo scores, while CU restorations were scored as alpha for marginal discoloration at the 36-month evaluation. IU and GP restorations had significantly higher proportions of bravo scores than CU ($p = 0.034$). At the 60-month evaluation, six (26.1%) IU and nine GP (32.1%) restorations were scored as bravo; these proportions of bravo scores were higher than that for CU ($p = 0.01$). McNemar's test showed significant changes in the IU and GP groups for marginal discoloration after 36 ($p = 0.031$ and $p = 0.031$, respectively) and 60 ($p = 0.031$ and $p = 0.004$, respectively) months.

Regarding surface texture, two (9.1%) CU, five (19.1%) IU, and six (20.0%) GP restorations exhibited bravo scores at the 36-month evaluation ($p = 0.554$). Two (10.0%) CU, seven (30.4%) IU, and six (21.4%) GP restorations were scored as bravo at the 60-month evaluation ($p = 0.284$). Regarding color match, two (9.1%) CU and one (3.3%) GP restorations showed bravo scores at the 36-month evaluation ($p = 0.457$). At the 60-month evaluation, two (10%) CU and one (3.6%) GP restorations exhibited bravo scores ($p = 0.366$), with no significant differences among the groups at any evaluation. None of the restorations demonstrated post-operative sensitivity or secondary caries.

The Kaplan–Meier analysis (Fig. 2) showed no significant difference in survival rate among the three adhesives (log rank, $p = 0.316$). The 60-month survival rates of CU, IU, and GP were 87%, 85.2%, and 96.6%, respectively.

Discussion

NCCLs commonly occur because of several etiological factors such as toothbrush abrasion, acid erosion, and stress [36]. These lesions are usually selected for bonding application and resin composite restoration studies. NCCLs have dentin and enamel margins, which allow evaluation of the bonding efficiency of adhesives to different surfaces. The bonding ability of universal adhesives demonstrated using different application methods have led them to be tested in several clinical and laboratory studies. The selective enamel etching technique, which avoids dentin etching, is preferred because it can prevent post-operative sensitivity [23, 37]. The phosphoric acid used in dentistry is in gel form, which makes it easy to apply to specific areas avoiding contact with other tissues. Liquid form of phosphoric acid could not be controlled during applications, so that gel form of phosphoric acid was preferred.

The experience of the dentist also affects the application procedure. Based on the American Dental Association (ADA) criteria, some studies reported provisional acceptance criteria for adhesives of a maximum of 5% restoration loss or microleakage after 6 months [26, 27]. In addition, the cumulative incidence of clinical failure should be tested in two independent clinical studies, and failure rates at 18 months must be less than 10% in terms of retention and microleakage [26, 27].

In the present study, three universal adhesives used in combination with a highly filled flowable resin composite were compared for the restoration of NCCLs. At 60 months, no significant difference in survival rate was observed among the tested universal adhesives. Regarding marginal discoloration, CU exhibited higher alpha scores than IU and GP after 60 months; however, all adhesives showed clinically acceptable results. Therefore, the null hypothesis was accepted.

Van Meerbeek et al. [38] reported that phosphoric acid etching of enamel effectively seals and protects the dentin-bond interface against degradation. The major problem with self-etch adhesives is marginal discoloration due to the mild acidity of these materials [39–41]. According to the manufacturers, the pH values of the universal adhesives used in the present study were mild (CU = 2.3; IU = 1.8) or intermediate (GP = 1.5). Because the adhesive with intermediate pH showed lower cumulative retention loss rate than universal adhesives with mild pH, it can be inferred that the acidity of adhesives affects the long-term results of the universal adhesives used in selective etch mode. However, GP showed a higher marginal discoloration rate than CU, which had a mild pH. Conversely, in a 4-year clinical trial, adhesives with different pH values demonstrated similar performance [10]. In addition, the pH values did not affect marginal adaptation in the present study, and no significant differences were observed among the groups for this criterion.

In the present study, the solvents of the universal adhesives may have affected the results. No marginal discoloration was observed in the ethanol-based adhesive, CU, which may be attributed to the low ethanol concentration (<20%) of this material. In contrast, IU and GP are acetone-based
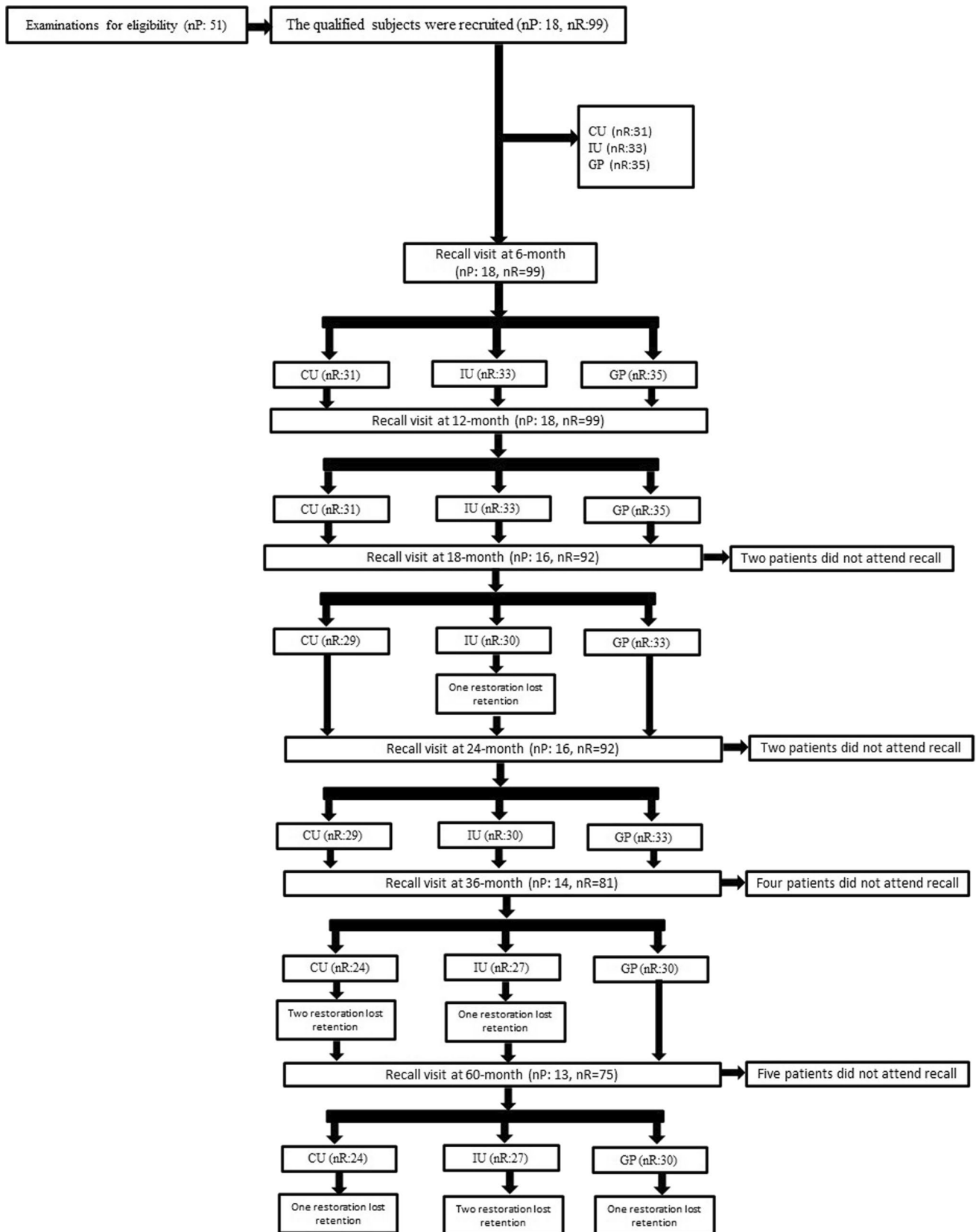
Fig. 1 Flow diagram of the study. nP, number of patients; nR, number of restorations; CU, Clearfil Universal Bond; IU, iBOND Universal; GP, G-Premio Bond

**Table 3** Clinical evaluation outcomes of different adhesive systems

Evaluation criteria	Score	Baseline			6 months n (%)			12 months n (%)			18 months n (%)			24 months n (%)			36 months n (%)			60 months n (%)		
		CU (n=31)	IU (n=33)	GP (n=35)	CU (n=31)	IU (n=33)	GP (n=35)	CU (n=31)	IU (n=33)	GP (n=35)	CU (n=29)	IU (n=31)	GP (n=33)	CU (n=29)	IU (n=30)	GP (n=33)	CU (n=24)	IU (n=27)	GP (n=30)	CU (n=21)	IU (n=25)	GP (n=29)
Retention	Alpha	31 (100)	33 (100)	35 (100)	31 (100)	33 (100)	35 (100)	31 (100)	33 (100)	35 (100)	29 (100)	30 (96.8)	33 (100)	29 (100)	30 (100)	33 (100)	22 (91.7)	26 (96.3)	30 (100)	20 (95.2)	23 (92.0)	28 (96.6)
	Bravo	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Charlie	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (3.2)	0 (0)	0 (0)	0 (0)	0 (0)	2 (8.3)	1 (3.7)	0 (0)	1 (4.8)	2 (8.0)	1 (3.4)
Marginal adaptation	Alpha	31 (100)	33 (100)	35 (100)	31 (100)	33 (100)	33 (94.3)	29 (93.5)	30 (90.9)	30ˢ (85.7)	27 (93.1)	27 (90.0)	27ˢ (81.8)	26 (89.7)	24 (80.0)	26 (78.8)	18 (81.8)	18 (69.2)	20 (66.7)	15 (75.0)	15 (65.2)	16 (57.1)
	Bravo	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (5.7)	2 (6.5)	3 (9.1)	5ˢ (14.3)	2 (6.9)	3 (10.0)	6ˢ (18.2)	3 (10.3)	6ˢ (20.0)	7ˢ (21.2)	4 (18.2)	8ˢ (30.8)	10ˢ (33.3)	5 (25.0)	8ˢ (34.8)	12ˢ (42.9)
	Charlie	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Marginal discoloration	Alpha	31 (100)	33 (100)	35 (100)	31 (100)	33 (100)	34 (97.1)	31 (100)	30 (90.9)	32 (91.4)	29 (100)	27 (90.0)	29 (87.9)	29 (100)	27 (90.0)	29 (87.9)	22 (100)	20 (76.9)	24 (80)	20 (100)	17 (73.9)	19 (67.9)
	Bravo	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (2.9)	0 (0)	3 (9.1)	3 (8.6)	0 (0)	3 (10.0)	4 (12.1)	0 (0)	3 (10.0)	4 (12.1)	0 (0)	6ˢ (23.1)	6ˢ (20.0)	0 (0)	6ˢ (26.1)	9ˢ (32.1)
	Charlie	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Surface texture	Alpha	31 (100)	33 (100)	35 (100)	29 (93.5)	33 (100)	35 (100)	29 (93.5)	30 (90.9)	30ˢ (85.7)	27 (93.1)	27 (90.0)	28 (84.8)	27 (93.1)	25 (83.3)	28 (84.8)	20 (90.9)	21 (80.8)	24 (80.0)	18 (90.0)	16 (69.6)	22 (78.6)
	Bravo	0 (0)	0 (0)	0 (0)	2 (6.5)	0 (0)	0 (0)	2 (6.5)	3 (9.1)	5ˢ (14.3)	2 (6.9)	3 (10.0)	5ˢ (15.2)	2 (6.9)	5ˢ (16.7)	5ˢ (15.2)	2 (9.1)	5ˢ (19.1)	6ˢ (20.0)	2 (10)	7ˢ (30.4)	6ˢ (21.4)
	Charlie	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Color match	Alpha	31 (100)	33 (100)	35 (100)	29 (93.5)	33 (100)	35 (100)	29 (93.5)	33 (100)	34 (97.1)	27 (93.1)	30 (100)	32 (97)	27 (93.1)	30 (100)	32 (97)	20 (90.9)	26	29 (96.7)	18 (90.0)	23 (100)	27 (96.4)
	Bravo	0 (0)	0 (0)	0 (0)	2 (6.5)	0 (0)	0 (0)	2 (6.5)	0 (0)	1 (2.9)	2 (6.9)	0 (0)	1 (3)	2 (6.9)	0 (0)	1 (3)	2 (9.1)	0 (0)	1 (3.3)	2 (10.0)	0 (0)	1 (3.6)
	Charlie	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Post-operative sensitivity	Alpha	31 (100)	33 (100)	35 (100)	31 (100)	33 (100)	35 (100)	31 (100)	33 (100)	35 (100)	29 (100)	30 (100)	33 (100)	29 (100)	30 (100)	33 (100)	22 (100)	26 (100)	30 (100)	20 (100)	23 (100)	28 (100)
	Bravo	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Charlie	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Secondary caries	Alpha	31 (100)	33 (100)	35 (100)	31 (100)	33 (100)	35 (100)	31 (100)	33 (100)	35 (100)	29 (100)	30 (100)	33 (100)	29 (100)	30 (100)	33 (100)	22 (100)	26 (100)	30 (100)	20 (100)	23 (100)	28 (100)
	Bravo	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Charlie	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

USPHS, US Public Health Service

ˢ Indicates significant difference in comparison with baseline according to Cochran's *Q* test followed by McNemar's test (*p* < 0.05)

CU, Clearfil Universal Bond; *IU*, iBOND Universal; *GP*, G-Premio Bond

Fig. 2 Survival curves for the tested groups (CU [Clearlfil Universal Bond], IU [iBOND Universal], GP [G-Premio Bond])
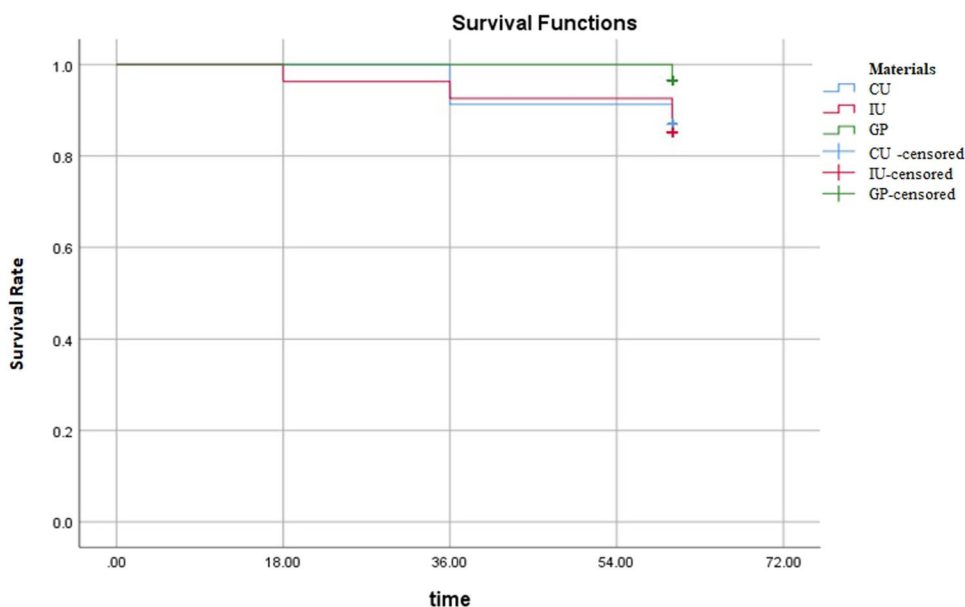
adhesives and exhibited marginal discoloration over time. In addition, IU and GP had higher solvent concentrations (25–50%) than CU. Previous studies showed that solvent content affects the bond strength of adhesives [42, 43]. Because acetone-based adhesives are likely to be thinner after evaporation than ethanol-based adhesives, they are more susceptible to degradation [44]. This might explain the higher bravo scores for marginal discoloration in the GP and IU groups than CU group after 60 months.

The addition of MDP monomer to adhesives may enhance their adhesion to dental structures through chemical adhesion to hydroxyapatite. Zhang et al. [45] showed that chemical bonding of MDP around the enamel crystallites of the etched enamel substrate significantly increased the enamel micro-tensile bond strength. Matos et al. [46] reported that an MDP containing universal adhesive exhibited better clinical outcomes and retention rates when using the etch-and-rinse than self-etch mode after 5 years. In the present study, the tested universal adhesives contained MDP monomers. Previous studies showed acceptable success rates for adhesives containing MDP [27, 47]. In addition, enamel etching increased the bonding ability of MDP monomers [45].

Self-etch adhesives show limited interaction with enamel, especially when ultra-mild adhesive solutions are used [40]. Therefore, marginal staining may occur over time. Etching of the enamel is recommended to improve the bonding, where poor etching of enamel allows food stains, which may lead to marginal pigmentation of restoration margins [30]. The benefits of enamel etching have been described in several in vitro studies [29, 30, 32]. Moreover, etching of the enamel improves the performance of universal adhesives [9, 34]. Similarly, in the present study, the use of the selective enamel etching mode resulted in high survival rates.

Even though enamel etching is important for the maintenance of restorations in laboratory studies [20–22], a clinical trial found that the application of self-etch adhesives to NCCLs with selective enamel etching only had a minor positive effect on marginal discoloration compared to the group without etching at 13 years [48]. However, Ruscel et al. [49] reported that an ethanol-based universal adhesive used in self-etch mode exhibited a high incidence of marginal discoloration at 18 months.

Some clinical studies reported inferior marginal discoloration or adaptation of universal adhesives over time [9, 26]. In a 2-year clinical investigation, a universal adhesive exhibited similar clinical performance between different application modes (self-etch and etch-and-rinse), and both groups showed increased marginal discoloration over time [26]. Loguercio et al. [9] also reported increased marginal staining of a universal adhesive in self-etch mode after 36 months. In contrast, Perdigao et al. [28] reported that an ethanol-based universal adhesive showed similar clinical performance (marginal adaptation and discoloration) among different application modes (self-etch, selective enamel etching, and etch-and-rinse) after 18 months. In the present study, even though selective enamel etching was applied, marginal adaptation and discoloration of the two universal acetone-based adhesives ([IU] and [GP]) worsened after 60 months. However, a 5-year clinical study observed better marginal staining and adaptation outcomes for another universal adhesive (Scotchbond Universal) using etch-and-rinse mode compared to self-etch mode [46].

The results showed that restorations performed using self-etch mode were 2.6-fold more likely to lose retention than those performed using etch-and-rinse mode, suggesting that selective enamel etching should be used for universal

adhesives [46]. In addition, Heintze et al. [50] performed a meta-analysis and reported that the clinical outcomes of NCCL restorations were affected by the bonding strategy and that the etch-and-rinse systems should be preferred over self-etch systems for better clinical outcomes.

Flowable resin composites have many uses, especially for small cavities, repair of large resin composite restorations, and as a shock absorber for conventional resin composites. In addition, they are preferred for the restoration of NCCLs because of their low viscosity and elasticity modulus [6]. Flowable resin composites have a filler loading of 37–53%, which is very low compared to that of conventional resin composites (50–70%) [51]. One study evaluated the mechanical properties (compressive, tensile, and biaxial flexure strengths) of flowable resin composites and reported that the flowable materials exhibited lower values than conventional resin composites; therefore, flowable resin composites should be used with caution, especially in areas with high stress [52]. The main reason why dentists prefer conventional resin composites over flowable resin composites is the low strength and questionable longevity of these latter materials, caused by their inferior mechanical properties [51]. These disadvantages have led manufacturers to develop a highly filled flowable resin composite. The highly filled flowable resin composite used in the present study has a higher elasticity modulus than conventional flowable resin composites [53]. The main advantage of this material is that it does not flow in the same way as a conventional flowable resin. In the present study, post-operative sensitivity was not observed, and the color match did not significantly change over time. The highly filled flowable resin composite has a 71% filler content [53], which may be useful to prevent polymerization shrinkage and improve clinical outcomes. In the present study, the highly filled flowable resin composite in combination with different adhesives showed good clinical outcomes, and none of the restorations cracked or exhibited chipping because of masticatory forces. All lost restorations were related to complete adhesion loss.

This clinical trial only included healthy participants with good periodontal health, which represents a limitation of the study; the inclusion of such participants may have led to better clinical outcomes. The 18 participants had different lifestyles, including in terms of diet, use of alcohol, coffee, tea, and cold drinks, smoking, and tooth-brushing; these differences may have affected the results. Future studies should include other types of participants. Patients with dental sensitivity, who may benefit from highly filled flowable resin composites in combination with universal adhesives applied in selective enamel etching mode, were excluded. These patients should be included in future studies to assess the outcomes of patients with NCCLs and hypersensitivity symptoms.

Conclusions

Within the limitations of this study, it was concluded that after 60 months:

(1) CU, IU, and GP showed similar marginal adaptation scores.
(2) IU and GP demonstrated higher marginal discoloration than CU.
(3) All the tested adhesives exhibited similar surface texture and color change scores.
(4) None of tested universal adhesives exhibited secondary caries or post-operative sensitivity, however.
(5) CU, IU, and GP demonstrated similar survival rates.

Declarations

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