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A New Dual-cure Universal Simplified Adhesive: 18-month Randomized Multicenter Clinical Trial

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Clinical Relevance

Non-carious cervical lesion restorations using a dual-cure universal adhesive in self-etch and etch-and-rinse mode showed satisfactory clinical performance after 18 months.

SUMMARY

Objectives: The objective of this multicenter, double-blind, split-mouth randomized clinical trial was to evaluate the clinical performance of a new dual-cure universal adhesive system (Futurabond U, Voco GmBH) when applied using different strategies over a period of 18 months.

Methods and Materials: Fifty patients participated in this study. Two hundred non-carious cervical lesions were restored using the adhesive Futurabond U according to four adhesive strategies (n=50 per group): only self-etch (SEE), selective enamel etching + self-etch (SET), etch-and-rinse with dry dentin (ERDry), and etch-and-rinse with wet dentin (ERWet). After the adhesive application, cavities were restored using Admira Fusion composite resin. These restorations were evaluated according

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to FDI World Dental Federation criteria for the following characteristics: retention/fracture, marginal adaptation, marginal staining, postoperative sensitivity, and caries recurrence.

Results: After 18 months, only four patients (12 months: one patient, n=4 restorations; and 18 months: three patients, n=12 restorations) were not evaluated. Fourteen restorations were lost after 18 months of clinical evaluation (four for SEE, three for SET, three for ERDry, and four for ERWet). The retention rates for 18 months (95% confidence interval) were 92% (81%-97%) for SEE, 94% (83%-97%) for SET, 94% (83%-97%) for ERDry, and 92% (81%-97%) for ERWet ($p>0.05$). Thirty-eight restorations were considered to have minor discrepancies in marginal adaptation at the 18-month recall (13 for SEE, 13 for SET, six for ERDry, and six for ERWet; $p>0.05$). Fourteen restorations were detected as a minor marginal discoloration at the 18-month recall (six for SEE, six for SET, one for ERDry, and one for ERWet; $p>0.05$). However, all were considered clinically acceptable. No restorations showed postoperative sensitivity or caries recurrence at the time.

Conclusion: The clinical performance of the Futurabond U did not depend on the bonding strategy used, and it was considered reliable after 18 months of clinical evaluation, although more marginal discrepancy was observed in the self-etch group.

INTRODUCTION

Non-carious cervical lesions (NCCLs) are commonly found specific tissue losses. They are reported in up to 60% of patients and are the most prevalent in the maxillary posterior teeth, mainly the premolars.[1,2] Development of NCCLs is a pathological process characterized by the loss of dental hard tissues near the cementoenamel junction[3] not caused by a bacterial agent. NCCLs could be caused by toothbrush abrasion, erosion caused by acids, and abfraction due to occlusal problems.[4] Recently, there have been worldwide increases in the prevalence and severity of NCCLs closely associated with people's lifestyles and the aging of the population.[5] Because NCCLs have been associated with other conditions, such as dentin hypersensitivity and gingival recession, as well as the loss of the dental mineralization continuum,[5] the restorative procedure is highly recommended.[6]

The current concepts of minimally invasive techniques associated with the need for simplification have prompted manufacturers to develop more user-friendly adhesive systems, by reducing the application steps and shortening the clinical application time.[6,7] The newest adhesives within this philosophy are called "universal," "multipurpose," or "multimode" adhesives.[8,9] This new class of adhesives could be used as a two-step etch-and-rinse or one-step self-etch, according to the dentist's preference and professional judgement regarding the selection of the adhesive strategy and number of steps.[10,11]

Although there is no official definition for what qualifies an adhesive system as a universal adhesive, the literature describes it is as a single-bottle adhesive that performs equally well with any adhesion strategy and bonds adequately to tooth structure as well as different direct and indirect restorative materials.[11]

Universal adhesives are similar to the simplified one-step self-etch adhesives but contain specific functional monomers to provide better bonding to the hard dental substrates. The best known of these monomers is 10-methacryloyloxydecyl dihydrogen phosphate (MDP). Several studies showed that MDP ionically bonds to dentin, forming hydrolytically stable calcium salts on hydroxyapatite (nanolayering), which promotes a more effective and stable bonding in water than that provided by other functional monomers.[12-14]

The inclusion of MDP allowed the development of more hydrophobic (ie, less hydrophilic) adhesives[15] as MDP is quite hydrophobic because of its long carbonyl chain.[16,17] Due to the inclusion of MDP and an optimized amount of water content, the manufacturers claimed to have balanced the hydrophobic and hydrophilic properties to ensure bonding at varying moisture levels.[18,19]

Although several universal adhesives have already been evaluated and shown reliable results through laboratory tests to establish the best application protocol for universal adhesives,[10,20,21] it is known that only clinical evaluations are the ultimate proof of clinical efficacy.[22]

Because of all these features, the clinical use of universal adhesives is increasing rapidly, and several clinical studies evaluating the universal adhesive systems were published with significant controversies.[23-30] For instance, some studies[26,30] showed that a better clinical performance was observed when the universal adhesives were applied in the etch-and-rinse approach. On the other hand, other

clinical studies showed that there were no differences for the universal adhesives applied in the self-etch or etch-and-rinse mode after 18-36 months of clinical service.[23-25,28,29] The same controversial results could be observed in the conclusion of the authors of two systematic reviews of clinical studies evaluating universal adhesives,[11,31] which indicates the need for more clinical studies to evaluate this new class of adhesive system.

Therefore, the objective of this multicenter, double-blind, randomized clinical trial was to evaluate the clinical behavior of a new dual-cure universal adhesive when applied using different application strategies during 18 months of clinical evaluation. The null hypothesis tested was that bonding to NCCLs using the self-etch strategy, compared to selective enamel etching or using the etch-and-rinse strategy with adhesive application on dry or moist dentin, would result in similar retention levels over 18 months of clinical service.

METHODS AND MATERIALS

Study Design

The description of the experimental design followed the Consolidated Standards of Reporting Trials (CONSORT) statement.[32] Written informed consent was obtained from all participants prior to starting the treatment. This clinical trial was registered in clinicaltrial.gov clinical registry (#NCT03244124). All participants were informed about the nature and objectives of the study, but they were not aware of which tooth received the specific treatments under evaluation.

Trial Design, Settings, and Location of Data Collection

This was a multicenter, double-blind, superiority, split-mouth, randomized clinical trial. The study was carried out in the clinics of the School of Dentistry of the State University of Ponta Grossa (PR, Brazil) and the Federal University Fluminense (Polo de Nova Friburgo, RJ, Brazil) from October 2016 to November 2016.

Recruitment—Patients were recruited as they sought treatment in the dental clinics of both universities. No advertisement was used for participant recruitment. Patients were recruited in the order in which they reported for the screening session, thus forming a sample of convenience.

Eligibility Criteria—A total of 120 participants were examined by two calibrated dental residents to check if they met the inclusion and exclusion criteria in each university (Figure 1). The evaluations were performed using a mouth mirror, an explorer, and a periodontal probe. Participants had to be in good general health, be at least 18 years old, have an acceptable oral hygiene level, and present at least 20 teeth under occlusion.

Participants were required to have at least four NCCLs to be restored in four different teeth. These lesions had to be nonretentive, be deeper than 1 mm, and involve both the enamel and dentin of vital teeth without mobility. The cavosurface margin could not involve more than 50% of enamel.[33] Patients who had extremely poor oral hygiene used orthodontic devices, had severe or chronic periodontitis, or had heavy bruxism habits were excluded from the study as they would need to receive other treatments before restorative intervention. Also, participants with known allergy to resin-based materials or any other material used in this study, pregnant or breastfeeding women, or participants under chronic use of anti-inflammatory, analgesic, and psychotropic drugs were not be included in the study.

Sample-size Calculation

The annual retention rate for one-step self-etch adhesives in NCCLs was reported to be 4.4% in a recent systematic review.[6] Considering that this decline follows a linear trend, the overall retention rate of one-step self-etch adhesives is approximately 78% after 5 years of clinical service. With an α of 0.05, a power of 80%, and a two-sided test, the minimal sample size was 50 restorations in each group in order to detect a difference of 25% among the test groups.

Random Sequence Generation and Allocation Concealment

The randomization was done on an intraindividual basis so that each subject ended up with four restorations, each one resulting from one of all possible combinations of adhesive strategy and roughening procedure. These randomization schemes were performed using software available at http://www.sealedenvelope.com.

A staff member not involved in the research protocol performed the randomization process with computer-generated tables. Details of the allocated groups were recorded on cards contained in sequentially numbered, opaque, sealed envelopes. Opening the envelope only on the day of the restorative procedure guaranteed concealment of the random sequence. In all cases, the tooth with the highest

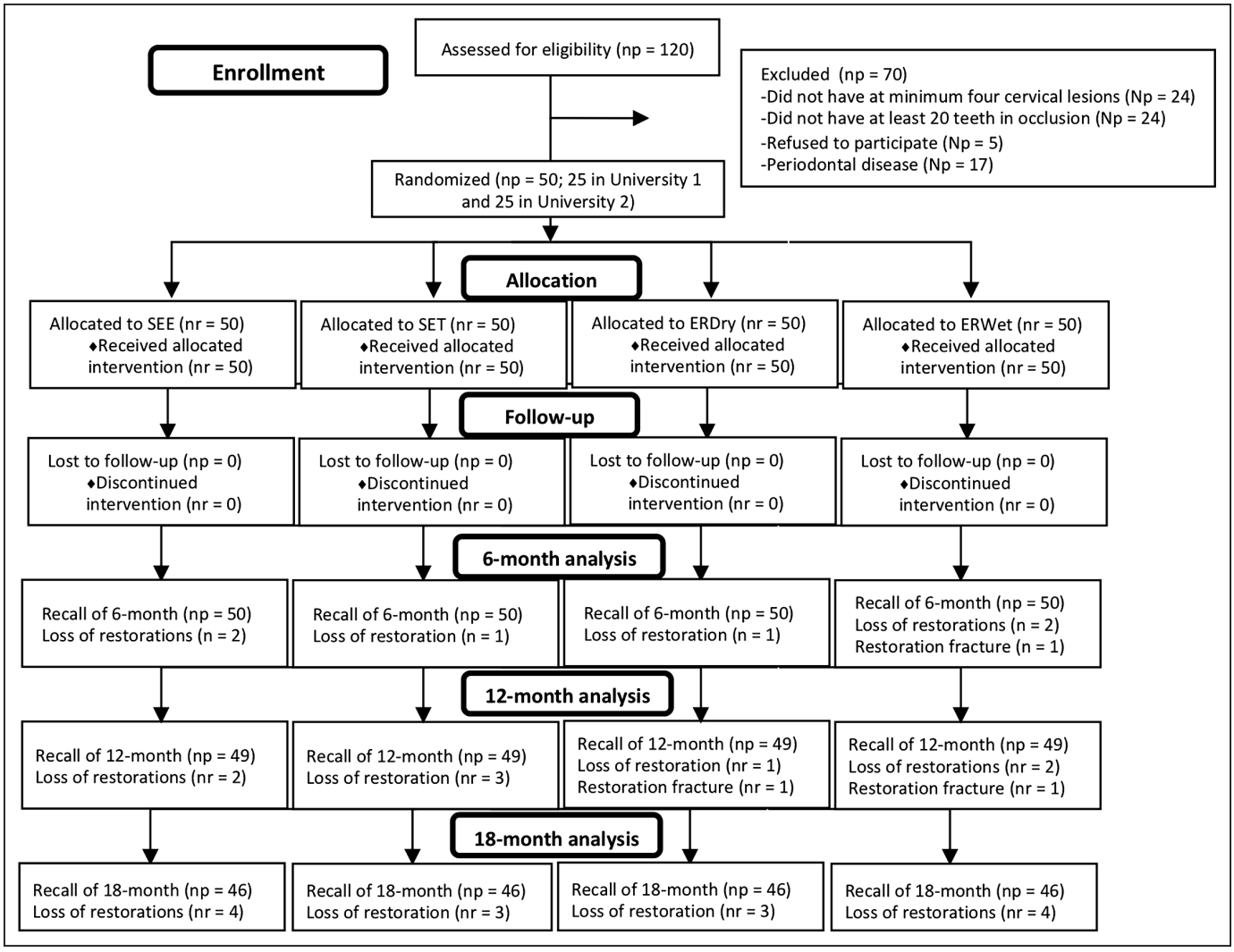

Figure 1. *Flowchart of the experimental design.*

tooth number received the treatment described first, whereas the tooth with the next number in sequence received the treatment mentioned second, with placement continuing in a similar manner until the fourth tooth (for the patients with four teeth needing treatment). All restorations in the same subject were always placed in different sextants.

Interventions: Restorative Procedure

All the patients selected for this study received dental prophylaxis with a suspension of pumice and water in a rubber cup and signed an informed consent form two weeks before the restorative procedures. The degree of sclerotic dentin from the NCCLs was measured according to the criteria described by Swift and others[34] (Table 1). The cavity dimensions in millimeters (height, width, and depth), the geometry of the cavity (evaluated by profile photograph and labeled at $<45°$, 45° to 90°, 90° to $<135°$, and $>135°$),[35] the presence of an antagonist, and the presence of attrition facets were observed and recorded. Preoperative sensitivity was also evaluated by applying air for 10 seconds from a dental syringe placed 2 cm from the tooth surface and with an explorer. These features were recorded to allow comparison of the baseline features of the dentin cavities among experimental groups.

To calibrate the restorative procedure, the study director of each center (MOB and ADL) placed one restoration from each group to identify all steps involved in the application technique. Then, the four operators (EGA, FW, TM and JJS), who were resident dentists with more than five years of clinical experience in operative dentistry, two in each center,

Table 1: *Dentin Sclerosis Scale*[a]

Category	Criteria
1	No sclerosis present; dentin is light yellowish or whitish, with little discoloration; dentin is opaque, with little translucency or transparency
2	More sclerosis than in category 1 but less than halfway between categories 1 and 4
3	Less sclerosis than in category 4 but more than halfway between categories 1 and 4
4	Significant sclerosis present; dentin is dark yellow or even discolored (brownish); glassy appearance, with significant translucency or transparency evident

[a] *Adapted from Swift and others.*[34]

placed four restorations, one of each group, under the supervision of the study director in a clinical setting. The restoration failures were shown to the operators before starting the study. At this point, the operators were considered calibrated to perform the restorative procedures. The operators restored all teeth. All participants received four restorations, one for each experimental group in different lesions previously selected according to the inclusion criteria.

Before restorative procedures, the operators anesthetized the teeth with a 3% mepivacaine solution (Mepisv, Nova DFL, Rio de Janeiro, Brazil) and cleaned all lesions with pumice and water in a rubber cup (No. 8040RA and No. 8045RA, KG Sorensen, Barueri, Brazil) followed by rinsing and drying. Then, shade selection was made using a shade guide. After a rubber dam was placed, the new universal adhesive system Futurabond U (Voco, GmbH, Cuxhaven, Germany) was applied as described later. The compositions, application modes, and batch numbers are described in Tables 2 and 3.

Self-etch Group (SEE)—One coat of adhesive was gently scrubbed on the entire enamel and dentin surface for approximately 20 seconds, according to the manufacturer's recommendations (Table 3). The adhesive was then evaporated by gentle air stream for 5 seconds and light cured for 10 seconds at 1200 mW/cm^2 (Bluephase 20i, Ivoclar Vivadent, Schaan, Liechtenstein).

Self-etch Associated With Selective Enamel Etching Group (SET)—The 35% phosphoric acid (Vococid, Voco) was applied for 30 seconds only in enamel. Then, cavities were rinsed and air-dried, until dentin was kept visibly dry. The adhesive system was applied as described in the self-etch group (Table 3). Solvent evaporation and light curing procedures were also the same.

Etch-and-rinse Dry Dentin Group (ERDry)—The 35% phosphoric acid (Vococid) was applied for 30 seconds (enamel) and 15 seconds (dentin). Then, cavities were rinsed and air-dried, until dentin was kept visibly dry. The adhesive system was applied as described in the self-etch group (Table 3). Solvent evaporation and light curing procedures were also the same.

Etch-and-rinse Wet Dentin Group (ERWet)—The 35% phosphoric acid (Vococid) was applied for 30 seconds (enamel) and 15 seconds (dentin). Then, cavities were rinsed and slightly air-dried, keeping visible dentin moist. The adhesive system was applied as described in the self-etch group (Table 3). Solvent evaporation and light curing procedures were also the same.

After adhesive application, the resin composite Admira Fusion unidose (Voco) was used in up to three increments, inserted directly in the cavity with a Centrix device (Centrix, Shelton, CT, USA) and each one being light cured for 10 seconds at 1200 mW/cm^2. The restorations were finished immediately with fine and extra-fine No. 2200 diamond burs (KG Sorensen) and polished with Jiffy polisher (Ultradent) under constant water-cooling.

Calibration Procedures for Clinical Evaluation

For training purposes, two experienced and calibrated examiners in each center (FSC, LAP, AR and

Table 2: *Composition and Batch Number of Materials Used in the Restorative Procedures*

Material (Manufacturer)	Batch Number	Composition
Futurabond U (Voco GmbH, Cuxhaven, Germany)	1609415	35% phosphoric acid (Vococid): 35% phosphoric acid Adhesive: HEMA, Bis-GMA, HEDMA, acidic adhesive monomer,[a] urethane dimethacrylate, catalyst, silica nanoparticles, ethanol
Admira Fusion (Voco GmbH, Cuxhaven, Germany)	Shade A2: 1607524; Shade A3: 1606252; Shade A3,5: 1605482	Resin matrix: aromatic and aliphatic dimethacrylates, methacrylate-functionalized polysiloxane Inorganic filler: Ba-Al-glass, pyrogenic SiO2, filler load: 78 mass %. Photoinitiator: camphorquinone. Synergist: NI

Abbreviations: Bis-GMA: Bisphenol-A-glycidyl dimethacrylate; HEDMA: 1,6-hexanediol dimethacrylate; HEMA: 2-hydroxyethyl methacrylate.
[a] *Acidic adhesive monomer in the composition of Futurabond U is 10-MDP: 10-methacryloyloxydecyl dihydrogen phosphate according to personal communication with Dr Martin Danebrock (January 30, 2018)*

Table 3: *Application Mode of the Adhesive System in the Groups* [a]

Group	Application Mode			
	Etch		Adhesive	Resin Composite
Self-etch (SEE)	No	Keep dentin dry (do not over dry)	1. Activate single-dose adhesive package; 2. Apply adhesive to the cavity surface with Voco Single Tim Brush for 20 s with vigorous agitation; 3. Gently air dry for 5 s; 4. Light cure for 10 s at 1200 mW/cm^2.	Insert in the cavity at increases of up to 1 mm and light-cure each area of the surface of the restoration with a dental curing light appliance (wavelength of 470 nm, light power of 1200 mW/cm^2) for 30 s.
Self-etch associated to selective enamel etching (SET)	Apply etchant *only* in enamel (30 s), rinse for 30 s, air dry to remove excess water			
Etch-and-rinse, dentin dry (ERDry)[b]	Apply etchant in enamel (30 s) and dentin (15 s), rinse for 30 s, air dry to remove excess water			
Etch-and-rinse, dentin wet (ERWet)		Keep dentin wet		

[a] *According to the manufacturer's instructions.*
[b] *Manufacturer does not indicate application in dry dentin.*

ADL) observed 10 photographs that were representative of each score for each criterion. They evaluated 10 to 15 patients each on two consecutive days. These subjects had cervical restorations but were not part of this project. An intraexaminer and interexaminer agreement of at least 85% was necessary before beginning the evaluation.[36]

*Blinding*The examiners were not involved with the restoration procedures and therefore blinded to the group assignment. Patients were also blinded to group assignment in a double-blind randomized clinical trial design.

*Clinical Evaluation*An individual, standardized, paper case report form was used for each evaluator at each recall time so that evaluators were kept blinded to earlier evaluations during the follow-up recalls. The restorations were evaluated by FDI World Dental Federation criteria[37,38] and the classical US Public Health Service (USPHS) criteria (adapted by Bittencourt and others[39]) at baseline and after 6,12, and 18 months of clinical service. Only the clinically relevant measures for evaluation of adhesive performance were used and scored (Tables 4 and 5). The primary clinical endpoint was restoration retention/fracture, but the following secondary endpoints were also evaluated: marginal staining, marginal adaptation, postoperative sensitivity, and recurrence of caries. The evaluation of spontaneous postoperative sensitivity was performed one week after the restorative procedure by asking patients if they experienced any pain during the period.

These variables were ranked according to FDI criteria into clinically very good, clinically good, clinically sufficient/satisfactory, clinically unsatisfactory but repairable, and clinically poor (replacement required).[37,38] In the case of marginal staining and marginal adaptation, the semiquantitative criteria (SQUACE) proposed by Hickel and others[37,38] was used. Each evaluator outlined the extent of the observed event on the sketch of each restoration using a pen according to defined criteria (marginal staining and marginal adaptation); after that, each margin was assessed quantitatively as a proportion of the total length of the margin. Also, all mentioned variables previously described were evaluated by USPHS criteria into Alpha, Bravo, and Charlie.[36]

Both examiners evaluated all the restorations once and independently. When disagreements occurred during the evaluations, they had to reach a consensus before the participant was dismissed. The restoration retention rates were calculated according to the American Dental Association guidelines.[40] Cumulative failure percentage = $[(PF + NF) / (PF + RR)] \times 100\%$, where PF is the number of previous failures before the current recall, NF is the number of new failures during the current recall, and RR is the number of currently recalled restorations.

Statistical Analysis

The statistical analyses followed the intention-to-treat protocol according to CONSORT (Consolidated Standards of Reporting Trials) suggestion.[32] Descriptive statistics were used to describe the distributions of the evaluated criteria. Statistical analysis for each individual item was performed for each evaluation criteria (FDI and USPHS criteria). The differences in the ratings of the four groups after 6, 12, and 18 months were tested with the Friedman repeated-measures analysis of variance by rank, and differences in the ratings of each group at baseline and after 6, 12, and 18 months were evaluated using the Wilcoxon test. Data from SQUACE after 18 months of clinical service was evaluated with the

Table 4: *FDI Criteria Used for Clinical Evaluation*[37,38]

	Esthetic Properties	Functional Properties		Biological Properties	
	1. Staining Margin	**2. Fractures and Retention**	**3. Marginal Adaptation**	**4. Postoperative (Hyper-)sensitivity**	**5. Recurrence of Caries**
1. Clinically very good (A)	1.1 No marginal staining	2.1 Restoration retained, no fractures/cracks	3.1 Harmonious outline, no gaps, no discoloration	4.1 No hypersensitivity	5.1 No secondary or primary caries
2. Clinically good (B) (after correction very good	1.2 Minor marginal staining, easily removable by polishing	2.2 Small hairline crack	3.2.1 Marginal gap (50 μm). 3.2.2 Small marginal fracture removable by polishing	4.2 Low hypersensitivity for a limited period of time	5.2 Very small and localized demineralization. No operative treatment required
3 Clinically sufficient/ satisfactory (C) (minor shortcomings with no adverse effects but not adjustable without damage to the tooth)	1.3 Moderate marginal staining, not esthetically unacceptable	2.3 Two or more or larger hairline cracks and/or chipping (not affecting the marginal integrity)	3.3.1 Gap <150 μm not removable 3.3.2. Several small enamel or dentin fractures	4.3.1 Premature/ slightly more intense 4.3.2 Delayed/weak sensitivity; no subjective complaints, no treatment needed	5.3 Larger areas of demineralization, but only preventive measures are necessary (dentin not exposed)
4. Clinically unsatisfactory (D) (repair for prophylactic reasons)	1.4 Pronounced marginal staining; major intervention necessary for improvement	2.4 Chipping fractures, which damage marginal quality; bulk fractures with or without partial loss (less than half of the restoration)	3.4.1 Gap >250 μm or dentin/base exposed. 3.4.2. chip fracture damaging margins 3.4.3 Notable enamel or dentin wall fracture	4.4.1 Premature/ very intense 4.4.2 Extremely delayed/weak with subjective complaints 4.4.3 Negative sensitivity; intervention necessary but not replacement	5. 4 Caries with cavitation (localized and accessible and can be repaired)
5. Clinically poor (E) (replacement necessary)	1.5 Deep marginal staining not accessible for intervention	2.5 (Partial or complete) loss of restoration	3.5 Filling is loose but *in situ*	4.5 Very intense, acute pulpitis or nonvital; endodontic treatment is necessary and restoration has to be replaced	5.5 Deep secondary caries or exposed dentin that is not accessible for repair of restoration

Table 5: *Modified USPHS Criteria According to Bittencourt and Others*[39]

	Marginal Staining	**Retention**	**Fracture**	**Marginal Adaptation**	**Postoperative Sensitivity**	**Recurrence of caries**
Alpha	No discoloration along the margin	Retained	None	Restoration is continuous with existing anatomic form	No postoperative sensitivity directly after the restorative process and during the study period	None evidence of caries contiguous with the margin
Bravo	Slight and superficial staining (removable, usually localized)	Partially retained	Small chip, but clinically acceptable	Detectable V-shaped defect in enamel only; catches explorer going both ways	-	-
Charlie	Deep staining cannot be polished away	Missing	Failure due to bulk restorative fracture	Detectable V-shaped defect to dentin-enamel junction	Sensitivity present at any time during the study period	Evidence of presence of caries

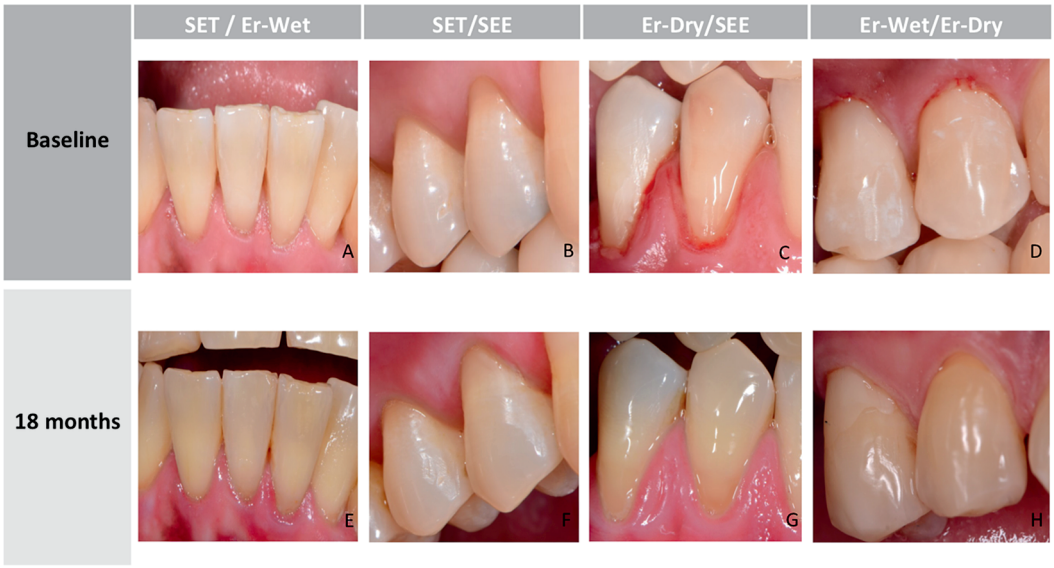

Figure 2. *Examples of restorations after baseline and 18 months of clinical evaluation. All restorations were scored as clinically very good at baseline (A-D; FDI criteria). Teeth 23 (E; ErWet group), 12 (F; SET group), 28 (G; ErDry group), and 29 (G; SEE group) were scored as clinically very good (FDI criteria for marginal adaptation). Teeth 24 (E; SET group), 13 (F; SEE group), and 6 (H; ErWet group) were scored as clinically good (FDI criteria for marginal adaptation). Tooth 5 was scored as clinically poor (H; ErDry group; FDI criteria for marginal adaptation).*

Kruskall-Wallis test. The Cohen kappa statistic was used to test interexaminer agreement. In all statistical tests, we preset the level of significance to 5%.

RESULTS

General Results

The restorative procedures were implemented exactly as planned, and no modification was performed. Of the 120 patients examined for eligibility, 70 were not enrolled in the study because they did not fulfill the inclusion criteria. Thus, a total of 50 subjects (23 men and 27 women) were selected. Two hundred restorations were placed, 50 for each group (Figure 1).

All baseline details relative to the research subjects and characteristics of the restored lesions are displayed in Table 6. The overall Cohen kappa statistic showed excellent agreement between the examiners at the 6-, 12-, and 18-month (0.82) follow-ups. All research subjects were evaluated at baseline and at the 6-month recall. One subject moved to a new city and was not included in the 12-month recall rate, and another three subjects did not attend the18-month recall. Some examples of restorations after baseline and 18 months of clinical evaluation are depicted in Figure 2.

Retention/Fracture

Seven restorations were lost or fractured after 6 months of clinical evaluation (two for SEE, one for SET, one for ERDry, and three for ERWet). According to both evaluation criteria, the 6-month retention rates (95% confidence interval [CI]) were 96% (86%-98%) for SEE, 98% (89%-99%) for SET, 98% (89%-99%) for ERDry, and 94% (83%-97%) for ERWet with no statistical difference identified between any pair of groups ($p>0.05$; Tables 7 and 8). When the data from the 6-month results from each group were compared with the baseline findings, no significant difference was found ($p>0.05$; Tables 7 and 8).

Ten restorations were lost or fractured after 12 months of clinical evaluation (two for SEE, three for SET, two for ERDry, and three for ERWet). According to both evaluation criteria, the 12-month retention rates (95% CI) were 96% (86%-98%) for SEE, 94% (83%-97%) for SET, 96% (86%-98%) for ERDry, and 94% (83%-97%) for ERWet with no statistical difference identified between any pair of groups ($p>0.05$; Tables 7 and 8). When the data from the 12-month results from each group were compared with the baseline findings, no significant difference was found ($p>0.05$; Tables 7 and 8).

Fourteen restorations were lost after 18 months of clinical evaluation (four for SEE, three for SET, three for ERDry, and four for ERWet). According to both evaluation criteria, the 18-month retention rates (95% CI) were 92% (81% to 97%) for SEE, 94% (83% to 97%) for SET, 94% (83% to 97%) for ERDry, and 92% (81% to 97%)for ERWet, with no statistical difference identified between any pair of groups ($p>0.05$; Tables 7 and 8). When the data from

Table 6: *Characteristics of the Research Participants and the NCCLs by Experimental Group*

Characteristics of Research Participants	No. of Participants			
Gender distribution				
Male	23			
Female	27			
Age distribution (y)				
20-29	3			
30-39	3			
39-49	20			
>49	24			
Characteristics of NCCLs	**No. of Lesions**			
	SEE	**SET**	**ERDry**	**ERWet**
Shape (degree of angle)				
<45	0	0	0	0
45-90	8	10	13	6
90-135	17	13	15	17
>135	25	27	22	27
Cervico-incisal height (mm)				
<1.5	14	17	17	15
1.5-2.5	15	13	14	17
2.5-4.0	12	8	12	11
>4.0	9	12	7	7
Degree of sclerotic dentin				
1	29	28	28	31
2	13	14	11	11
3	6	7	9	6
4	2	1	2	2
Presence of antagonist				
Yes	41	49	42	44
No	9	1	8	6
Attrition facet				
Yes	37	38	40	43
No	13	12	10	7
Preoperative sensitivity (spontaneous)				
Yes	13	11	11	13
No	37	39	39	37
Preoperative sensitivity (air dry)				
Yes	17	13	13	15
No	33	37	37	35
Tooth distribution				
Anterior				
Incisor	9	12	10	11
Canines	8	5	10	9
Posterior				
Premolar	21	24	23	21
Molar	12	9	7	9
Arch distribution				
Maxillary	25	27	24	26
Mandibular	25	23	26	24

Abbreviations: ERDry, etch-and-rinse, dry dentin; ERWet, etch-and-rinse, wet dentin; NCCL, non-carious cervical lesion; SEE, self-etch without selective enamel etching; SET, self-etch with selective enamel etching.

the 18-month results from each group were compared with the baseline findings, no significant difference was found ($p>0.05$; Tables 7 and 8).

Marginal Adaptation

Twenty-four restorations were considered to have minor discrepancies in marginal adaptation at the 6-month recall using the FDI criteria (eight for SEE, nine for SET, four for ERDry, and three for ERWet; Table 7). No significant difference was detected between any pair of groups at the 6-month recall for either evaluation criteria ($p>0.05$; Table 7). When the USPHS criteria were used, three restorations were scored as Bravo for marginal adaptation (two for SEE and one for SET; $p>0.05$; Table 8). When the baseline and 6-month data from the FDI evaluation were compared, a significant difference was only observed between SEE and SET ($p<0.05$; Table 8). No significant difference was detected when the baseline and 6-month data were compared for ERDry and ERWet ($p>0.05$; Table 8).

Thirty-one restorations were considered to have minor discrepancies in marginal adaptation at the 12-month recall using the FDI criteria (12 for SEE, 10 for SET, five for ERDry, and four for ERWet; Table 7). No significant difference was detected between any pair of groups at the 12-month recall for either evaluation criteria ($p>0.05$; Table 7). When the USPHS criteria were used, nine restorations were scored as Bravo for marginal adaptation (four for SEE, three for SET, one for ERDry, and one for ERWet; $p>0.05$; Table 8). When the baseline and 12-month data from the FDI evaluation were compared, a significant difference was observed only between SEE and SET ($p<0.05$; Table 8). No significant difference was detected when the baseline and 12-month data were compared for ERDry and ERWet ($p>0.05$; Table 8).

Thirty-eight restorations were considered to have minor discrepancies in marginal adaptation at the 18-month recall using the FDI criteria (13 for SEE, 13 for SET, six for ERDry, and six for ERWet; Table 7). When the baseline and 18-month data from the FDI evaluation were compared, a significant difference was observed only between SEE and SET ($p<0.05$; Table 7). No significant difference was detected when the baseline and 18-month data were compared for ERDry and ERWet ($p>0.05$; Table 7). When the USPHS criteria were used, 16 restorations were scored as Bravo for marginal adaptation (six for SEE, six for SET, two for ERDry, and two for ERWet; $p>0.05$; Table 8). No significant difference was detected when the baseline and 18-month data from

Table 7: *Number of Evaluated Restorations for Each Experimental Group Classified According to FDI Criteria*[37,38]

FDI Criteria	Status[a]	6 Months				12 Months				18 Months			
		SEE	SET	ERDry	ERWet	SEE	SET	ERDry	ERWet	SEE	SET	ERDry	ERWet
Marginal staining	A	48	49	49	47	42	41	45	44	32	33	39	37
	B	-	-	-	-	03	04	01	01	06	06	01	01
	C	-	-	-	-	-	-	-	-	-	-	-	-
	D	-	-	-	-	-	-	-	-	-	-	-	-
	E	-	-	-	-	-	-	-	-	-	-	-	-
Fractures and retention	A	48	49	49	47	45	45	46	45	38	39	40	38
	B	-	-	-	-	-	-	-	-	-	-	-	-
	C	-	-	-	-	-	-	-	-	-	-	-	-
	D	-	-	-	01	-	-	01	01	-	-	-	-
	E	02	01	01	02	02	03	01	02	04	03	03	04
Marginal adaptation	A	40	40	45	44	33	35	41	41	25	26	34	32
	B	08	09	04	03	12	10	05	04	10	11	06	06
	C	-	-	-	-	-	-	-	-	03	02	-	-
	D	-	-	-	-	-	-	-	-	-	-	-	-
	E	-	-	-	-	-	-	-	-	-	-	-	-
Postoperative (hyper-) sensitivity	A	48	49	49	47	45	45	46	45	38	39	40	38
	B	-	-	-	-	-	-	-	-	-	-	-	-
	C	-	-	-	-	-	-	-	-	-	-	-	-
	D	-	-	-	-	-	-	-	-	-	-	-	-
	E	-	-	-	-	-	-	-	-	-	-	-	-
Recurrence of caries	A	48	49	49	47	45	45	46	45	38	39	40	38
	B	-	-	-	-	-	-	-	-	-	-	-	-
	C	-	-	-	-	-	-	-	-	-	-	-	-
	D	-	-	-	-	-	-	-	-	-	-	-	-
	E	-	-	-	-	-	-	-	-	-	-	-	-

Abbreviations: FDI, World Dental Federation; ERDry, etch-and-rinse, dry dentin; ERWet, etch-and-rinse, wet dentin; SEE, self-etch without selective enamel etching; SET, self-etch with selective enamel etching.
[a] *A, clinically very good; B, clinically good; C, clinically sufficient / satisfactory; D, clinically unsatisfactory; E, clinically poor.*

the USPHS evaluation criteria were compared ($p>0.05$; Table 7). No significant difference was detected between any pair of groups at the 18-month recall for either evaluation criteria ($p>0.05$; Tables 7 and 8). At the 18-month evaluation, the results of SQUACE showed that, usually, the marginal discrepancy was observed in less than 10% or between 10% and 30% of the restorations' margins (Table 9). Only the SEE group showed a statistical difference at the 18-month recall, compared with other experimental groups ($p>0.05$; Table 9).

Marginal Discoloration

Marginal staining was not observed in any restoration at the 6-month recall using the FDI and USPHS criteria. However, nine restorations presented with minor marginal discoloration at the 12-month recall using the FDI criteria (three for SEE, four for SET, one for ERDry, and one for ERWet; Table 7). When the USPHS criteria were applied, only two restorations (one for SEE and one for SET; Table 8) were considered to show marginal discoloration. When the baseline and 12-month data for both criteria were compared, no significant difference was detected ($p>0.05$; Tables 7 and 8).

After 18 months of clinical evaluation, 14 restorations were detected with a minor marginal discoloration using the FDI criteria (six for SEE, six for SET, one for ERDry, and one for ERWet; Table 7). When USPHS criteria were applied, only four restorations (two for SEE and two for SET; Table 8) were considered to show marginal discoloration. When the baseline and 18-month data for both criteria were compared, no significant difference was detected ($p>0.05$; Tables 7 and 8).

Other Parameters

No restorations had postoperative sensitivity to air at the 6-, 12-, and 18-month recalls using both

Table 8: *Number of Evaluated Restorations for Each Experimental Group According to the Modified USPHS Criteria*[39]

USPHS Criteria	6 Months				12 Months				18 Months			
	SEE	SET	ERDry	ERWet	SEE	SET	ERDry	ERWet	SEE	SET	ERDry	ERWet
Marginal staining												
Alpha	48	49	49	47	44	44	46	45	36	37	40	38
Bravo	-	-	-	-	01	01	-	-	02	02	-	-
Charlie	-	-	-	-	-	-	-	-	-	-	-	-
Retention												
Alpha	48	49	49	47	45	45	46	45	38	39	40	38
Bravo	-	-	-	-	-	-	-	-	-	-	-	-
Charlie	02	01	01	02	02	03	01	02	04	03	03	04
Fractures												
Alpha	48	49	49	47	45	45	46	45	38	39	40	38
Bravo	-	-	-	-	-	-	-	-	-	-	-	-
Charlie	-	-	-	01	-	-	01	01	-	-	-	-
Marginal adaptation												
Alpha	46	48	49	47	41	42	45	44	32	33	38	36
Bravo	02	01	-	-	04	03	01	01	06	06	02	02
Charlie	-	-	-	-	-	-	-	-	-	-	-	-
Postoperative (hyper-) sensitivity												
Alpha	48	49	49	47	45	45	46	45	38	39	40	38
Bravo	-	-	-	-	-	-	-	-	-	-	-	-
Charlie	-	-	-	-	-	-	-	-	-	-	-	-
Recurrence of caries												
Alpha	48	49	49	47	45	45	46	45	38	39	40	38
Bravo	-	-	-	-	-	-	-	-	-	-	-	-
Charlie	-	-	-	-	-	-	-	-	-	-	-	-

Abbreviations: USPHS, US Public Health Service; ERDry, etch-and-rinse, dry dentin; ERWet, etch-and-rinse, wet dentin; SEE, self-etch without selective enamel etching; SET, self-etch with selective enamel etching.

criteria. No restoration showed a recurrence of caries after 6, 12, and 18 months for either criteria.

DISCUSSION

The comparison of bonding techniques and adhesive systems is usually performed with NCCLs, as these lesions lack macromechanical retention; therefore, restoration loss occurs due to ineffective bonding, which is an objective and clinically important outcome for adhesive efficacy.[6,41] This is considered a true endpoint because if restorations are lost, none of the other parameters can be evaluated. The results of the present study showed that after 18 months of clinical service, restorations placed with Futurabond U had similar retention rates regardless of the use of phosphoric acid or wetness in the surface of the dental substrate of NCCLs; this leads us to accept the null hypothesis.

Table 9: *Number of Evaluated Restorations for Each Experimental Group According to the Adhesive Classified by SQUACE criteria*[a,37,38]

SQUACE criteria	SEE	SET	ERDry	ERWet
Less than 10%	02	12	05	05
Between 10% and 30%	11	01	01	01
Between 31% and 50%	-	-	-	-
Statistical Analysis	B	A	A	A

Abbreviations: ERDry, etch-and-rinse, dry dentin; ERWet, etch-and-rinse, wet dentin; SEE, self-etch without selective enamel etching; SET, self-etch with selective enamel etching; SQUACE, semiquantitative criteria.
[a] Different capital letters indicate statistically significant difference between groups ($p<0.05$).

In the present study, Futurabond U was applied after etching with phosphoric acid under dry or wet dentin (ERDry and ERWet) conditions. This took into account that the ideal universal adhesive would be one in which bonding to the tooth would not be influenced by clinically plausible variations in the surface moisture.[19] Unfortunately, although the wet-bonding technique is very popular among clinicians, the manufacturers' instructions for the surface wetness of the substrates after phosphoric acid etching are not precisely specified, making variability in the clinic even more likely.[42,43]

The rationale behind the wet-bonding technique is, after phosphoric acid etching (etch-and-rinse technique), it is important to keep the dentin moist to avoid the collapse of the exposed collagen matrix and, mainly, to guarantee the infiltration of the resin monomer into the demineralized dentin.[44] However, universal adhesives contain water in their composition to enable the self-etching potential, and several studies have already claimed that adhesives with a water concentration of 10% to 25% can re-expand the air-dried and collapsed collagen mesh to facilitate adhesive resin infiltration.[19,45,46] Therefore, keeping the dentin wet or visibly dry after the phosphoric acid application would not make a difference in the bonding quality when using a universal adhesive with this water concentration in the composition. Unfortunately, the exact water content of the Futurabond U was not disclosed by the manufacturer.

It is worth mentioning that the active application of Futurabond U also helps to infiltrate the adhesive in the collapsed collagen network because the pressure of the collapsed collagen in demineralized dentin allows better monomer diffusion inward as well as solvent diffusion outward.[47,48] The active application of the etch-and-rinse adhesives showed better clinical performance in adhesive restorations, even when the dentin was kept visibly dry, compared with passive application.[33,49]

The results of the present study allowed us to conclude that Futurabond U is tolerant to dentin moisture variation because of the similar retention rate of Futurabond U when applied on dry dentin (ERDry; 94%) or moist dentin (ERWet; 92%) after 18 months of clinical evaluation. Compared with the literature, the clinical behavior of Futurabond U when applied in the ERDry or ERWet condition could be considered very good and comparable to the universal adhesives evaluated in the same conditions.[23,26]

As discussed in the Introduction, the presence of specific functional monomers, such as MDP, in the universal adhesives is responsible for the chemical interaction with the dental hard tissues. Unfortunately, the use of phosphoric acid removes the calcium from dentin and may preclude any potential chemical bonding (nanolayering) between the calcium and phosphate groups in the adhesive. Similar immediate dentin bond strength results are shown when etch-and-rinse and self-etch approaches are compared.[50] However, the bonding ability of Futurabond U in the etch-and-rinse mode was significantly lower after water storage compared with Futurabond U applied in the self-etch mode.[50] Although extrapolation to clinical situations is not often recommended, the available research data suggest that etching dentin may not be the first choice for MDP-containing universal adhesives.[27]

In the safety data sheet of Futurabond U the manufacturer describes its functional monomer only as a phosphate mono-methacrylate, and this caused some confusion in previously published laboratory studies[51]. However, it has already been confirmed that MDP is present in the Futurabond U composition,[52] and this could be responsible for the higher retention rate of Futurabond U when applied in the self-etch mode (SEE and SET) after 18 months of clinical service, which is similar to the other universal adhesives available on the market.[23-25,29]

A frequent concern regarding universal adhesives when used in the self-etch mode is related to the lower potential of etching enamel,[53,54] resulting in a higher number of defective margins of the restorations and, consequently, the marginal staining at long-term follow-ups. In the present study, a closer view regarding the marginal adaptation data, mainly from the SEE group, showed that Futurabond U presented a lower percentage of marginal failures (30%) than found in previous studies when the SEE group was evaluated (47% to 57%).[23,24] Although Futurabond U could be considered a mild pH, self-etch adhesive (pH range 2-2.5), the adhesives evaluated in previous studies[23,24] are considered ultra-mild self-etch (pH>2.5). Therefore, it would be expected that Futurabond U should more adequately etch the enamel margins. However, no differences were observed in the enamel etching pattern when the mild and ultra-mild universal self-etch adhesives were compared.[19,53,55] Actually, Futurabond U showed similar bonding properties to the enamel (bond strength and *in situ* degree of conversion) compared with the ultra-mild universal adhesives applied in the self-etch mode.[24,53]

Several factors may be involved in the good marginal adaptation of a resin composite to the cavity. It was shown that the marginal cavity adaptation of resin restorations depends not only on material-related properties, such as the adhesive used, polymerization shrinkage, viscoelastic properties, and stiffness of the restorative material, but also on the individual treatment conditions, such as cavity size and geometry, restorative placement, and curing techniques.[56] Another factor is the method of resin composite application in the cavity. In this specific case, the resin composite was used in capsules, and applied directly to the cavity and not in syringes as in previous studies.[23-30] The use of

capsules decreases the presence of voids and porosities in the final restorations.[57,58] To the best of our knowledge, the effects of inserting resin composites in capsules or syringes on the clinical performance of the composite resin restorations are not known. Future clinical studies need to be done to evaluate the effect of inserting the resin composite in syringe versus capsule in the clinical performance of NCCL restorations.

It is worth mentioning that the percentage of marginal defects observed in several clinical studies that evaluated universal adhesives in NCCLs was still lower than in the present study.[30,59] This could be explained by the criteria used to evaluate the restorations. Although in the present study, FDI criteria were applied, the restorations were evaluated using a modified USPHS criteria in the other studies.[30,59] In a recent literature review,[60] it was shown that the use of FDI criteria for the clinical evaluation of direct restorations was more sensitive and precise in detecting minor failure compared with modified USPHS criteria.[23,24,26,27,49] A few restorations were observed with marginal adaptation problems when evaluated by USPHS criteria in the present study as well as in results of previous studies evaluating NCCL adhesive restorations with the same criteria.[23,24,30,59]

The use of selective etching of the enamel margins has been recommended prior to the application of self-etch adhesives to overcome this limitation.[61,62] However, note that the results of the present study showed no significant difference in the marginal adaptation when the SEE and SET groups were compared using USPHS and FDI criteria. This could be attributed to the low number of restorations with marginal defects, as previously described.

On the other hand, when SQUACE was applied,[37] some differences were observed between SEE and SET. Although SQUACE, in addition to the FDI criteria, has been proposed to improve the marginal quality evaluation,[37] only a few clinical trials have used this auxiliary method.[23,24,26] Perdigão and others[23] showed that, when SQUACE was used, SEE resulted in a significantly greater number of restorations, between 10% and 30% of the total length of the interface, showing a marginal discrepancy compared with the SET group or even compared with the ERWet and ERDry groups.

In the present study, when SQUACE was used, this same pattern was observed, as the SEE group showed a statistical difference at the 18-month recall rate compared with the other experimental groups. However, it is worth mentioning that all marginal defects observed in the present study were considered clinically acceptable and easily corrected by the clinician through a repolish of the restorations.[63] Future long-term clinical follow-up studies are still necessary to prove the results obtained in this study.

Finally, this clinical study had some limitations. The study was conducted in a university setting, with all restorations placed in an ideal scenario by four well-calibrated and supervised operators. In this setting, only motivated patients with a low caries risk were included. Therefore, future clinical studies need to evaluate the universal adhesives in a practice-based study, preferably in patients with high caries risk. Also, 18 months of clinical evaluation could be considered a medium-term follow-up. Therefore, future long-term follow-up studies need to be done. However, the fact that Futurabond U belongs to a very versatile and moisture tolerant universal adhesive category warranted this medium-term evaluation.

CONCLUSION

After 18 months in NCCLs, the clinical performance of Futurabond U was very good when used in the etch-and-rinse technique and maintaining dentin moisture or slightly drying the dentin. The clinical performance was also very good when Futurabond U was used in the self-etch mode associated with selective enamel etching, although more marginal discrepancy was observed in the self-etch mode.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Federal University Fluminense, Campus Nova Friburgo and State University of Ponta Grossa. The approval codes issued for this study are 165.357/2016 and 1.618.895/2016.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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