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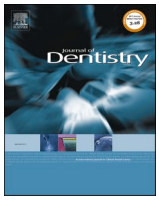

Clinical performance of posterior restorations using a universal adhesive over moist and dry dentin: A 36-month double-blind split-mouth randomized clinical trial

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ABSTRACT

Objectives: To evaluate the influence of dentin moisture on the clinical behavior of a universal adhesive on posterior teeth after 36 months of follow-up.
Methods: Forty-five patients participated in this study. Following a split-mouth design, three operators placed 90 Class I/Class II restorations over moist dentin (MD) or dry (DD) ($n = 45$) with resin composite (Filtek Bulk Fill) and a universal adhesive used in the etch-and-rinse mode (Single Bond Universal). Each restoration was evaluated according to the FDI and USPHS criteria (postoperative sensitivity, fracture and retention, marginal staining, marginal adaptation, and recurrence of caries) at baseline and after 6-, 12-, and 36 months. For statistical analysis, Kruskal Wallis analysis of variance rank ($\alpha = 0.05$) and Kaplan-Meier survival analysis were used.
Results: No significant difference between groups was observed in each FDI criterion after 36 months of clinical evaluation ($p > 0.05$). The retention rates (confidence interval 95 %) were 97.37 % (86.5 - 99.5) for both MD and DD without significant difference between them ($p > 0.05$). Eight restorations (MD = 4; DD = 4) showed minimal marginal staining defects ($p > 0.05$). Two restorations were lost (MD = 1; DD = 1). Fifteen restorations (MD = 8; DD = 7) presented minor marginal discrepancies according to the FDI criteria ($p > 0.05$).
Conclusion: The clinical performance of the universal adhesive when applied in etch-and-rinse mode was not influenced by dentin moisture in posterior bulk-fill composite restorations.
Clinical significance: The level of dentin moisture appears not to influence the clinical efficacy of a universal adhesive when applied using the etch-and-rinse technique in posterior composite resin restorations.

1. Introduction

Over the past decades, different materials have been used for direct restorations on posterior teeth [1]. Currently, the increase in esthetic demand is one of the several reasons why resin composites associated with adhesive systems are considered the material of choice for clinical procedures in restorative dentistry. Despite this, the mean survival rate of composite restorations is about 87 % after ten years, where bulk fractures were considered the main failure reason, followed by caries lesions at the restorative margins [2]. Notably, the material of choice alone does not guarantee extended longevity; several factors like tooth-related, parafunctional habits, socioeconomics factors, and the clinician who undertakes the adhesive restorative procedures, play an important role [3].

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One of the adhesive techniques still used nowadays is the etch-and-rinse strategy, based on the micromechanical adhesion of the adhesive to the dental substrate, involving the prior application of 30–40 % orthophosphoric acid to remove the smear layer, demineralize dentin, and expose the microporous collagen fibrils network [4]. While the achieved adhesion is considered clinically favorable, some potential issues have been associated with this technique, such as maintaining the collagen fibrils spaces for a proper monomer infiltration [5], and this scenario getting even worse after the dentin air-drying resulting in the collapse of the collagen fibrils decreasing the interfibrillar spaces [6], producing an incomplete monomer diffusion and the subsequent hydrolytic degradation of the exposed collagen network [7].

In this sense, maintaining dentin moist has been considered an important technique to enhance monomer infiltration and hybrid layer formation on the dry dentin after acid-etching, influencing composite restoration's bonding success when using etch-and-rinse adhesives [8]. However, in vitro studies showed conflicting findings regarding the impact of dentin moisture on the bonding efficacy of these adhesives, suggesting the influence of other factors such as adhesive composition and application mode as rubbing motion [9-15]. In terms of clinical trial evidence, no significant influence of dentin moisture was observed in the clinical performance of etch-and-rinse adhesives in non-carious cervical lesions after 18–24 months [16,17], as well as in posterior restorations after 36 months [18].

The most recent generation of adhesive systems, the universal adhesives, offer versatility to different clinical scenarios and the preferences of dentists regarding adhesive strategies: etch-and-rinse (ER), self-etch (SE), or selective enamel etching in self-etch protocols [19]. A key feature of most universal adhesives is the inclusion of 10-MDP in its composition. This functional monomer forms ionic bonds with calcium and hydroxyapatite after being ionized with water content on universal adhesives, thus offering superior chemical bonding capabilities [4]. Additionally, this increased water content compared to etch-and-rinse adhesives may act as a moisturizer, re-wetting collagen fibrils during application over dry dentin, being able to be applied in both moisture conditions [12].

However, some in vitro studies have shown conflicting findings on the influence of dentin moisture on the bond strength of universal adhesives when applied with the etch-and-rinse strategy [12,14,20], suggesting that it may be a product-dependent behavior. Few clinical studies have evaluated the impact of dentin moisture on the longevity of universal adhesive restorations, showing similar behavior in non-carious cervical lesions during the 36-month clinical evaluation [21-23], as well as in posterior restorations during the 12-month clinical assessments [24]. Therefore, there is a lack of evidence about the influence of dentin moisture on the universal adhesive clinical performance on posterior restorations over time.

Thus, the aim of this double-blind, split-mouth randomized clinical study was to evaluate the impact of dentin moisture on the clinical behavior of a universal adhesive applied in the etch-and-rinse mode on posterior teeth after 36 months of follow-up. The null hypotheses tested were: (1) dentin moisture will not influence the postoperative sensitivity rate when UA is applied in the etch-and-rinse mode in posterior teeth, and (2) dentin moisture will not influence other clinical parameters (fracture and retention, marginal staining, marginal adaptation, and recurrence of caries) when UA is applied in the etch-and-rinse mode in posterior teeth after a 36-month follow-up.

2. Methods and materials

2.1. Ethics approval and protocol registration

The Ethics Committee of the State University of Ponta Grossa/PR (Brazil) reviewed and approved this study under protocol number 1.752.848. This study was registered in the Clinical Trials Registry (RBR-83CD7J) and it was conducted and reported under the CONSORT statement [25].

2.2. Trial design, settings, and location of data collection

This was a double-blind (patient and examiner), split-mouth (two teeth of different groups per participant) randomized clinical trial. The study was conducted in the clinics of the School of Dentistry of the State University of Ponta Grossa/PR (Brazil) from October 2017 to December 2018, and the 36-month follow-up evaluation was conducted from May 2021 to December 2021.

2.3. Participants recruitment

Patients were recruited in the order in which they appeared for screening sessions in the university's dental clinics, thus forming a sample of convenience. Written advertisements were placed on the university's walls. Three calibrated dental residents recruited the patients and selected the teeth. The calibration process began before the screening sessions. On two consecutive days, the investigators clinically and radiographically evaluated ten teeth with class I and II lesions that would not be part of the study. After evaluation, inter- and intra-examiner agreements were calculated, and a score of at least 85 % was necessary for calibration [26]. All participants were informed about the study's nature and objectives, but they were unaware of what tooth received the specific treatment under evaluation. Written informed consent was obtained from all participants before starting treatment.

2.4. Eligibility criteria

The evaluations were performed using an intraoral mouth mirror, an explorer, and a periodontal probe. Participants had to be in good general health (ASA I, a normal healthy patient; and ASA II, a patient with mild systemic disease without substantive functional limitations) [27], at least 18 years old, with at least 20 teeth under occlusion and low caries risk. They needed to have at least two carious lesions and/or indications of replacement restorations with similar cavity types in different hemi-arches with depths $\geq$ 3 mm (diagnosed with an interproximal radiograph).

Participants with dental prostheses, severe or chronic periodontitis (teeth with probing pocket depth more than 4 mm with bleed on probing and clinical attachment loss more than 3 mm in more than four teeth) [28], extremely poor oral hygiene according to the Simplified Oral Hygiene Index (OHI-S) [29], parafunctional habits, continuous use of medication, patients undergoing bleaching treatments and patients who were pregnant were excluded from the study.

2.5. Sample size calculation

The sample size calculation was based on the absolute risk of spontaneous postoperative sensitivity in posterior resin composite restorations. According to the literature, the risk of post-operative sensitivity was approximately 30 % in deep and extensive restorations performed with etch-and-rinse adhesives [30-32]. Using a α of 0.05, a power of 80 %, and a two-sided test, the minimal sample size was 45 restorations per group (considering 20 % loss) to detect a 20 % difference between groups [18,24,33,34].

2.6. Randomization sequence generation, allocation concealment, and blinding

The randomization process was performed by a staff member not involved in the research study using a no-charge software available on the website http://www.sealedenvelope.com. Details of the allocated group were recorded on cards contained in sequentially numbered, opaque, sealed envelopes. The allocation assignment was revealed by opening the envelope on the day of the restorative procedure to prevent

selection bias. The tooth with the highest tooth number received the treatment described in the envelope, while the other tooth received the other treatment. The operator was not blinded to group assignments when administering interventions, though participants and examiners were blinded.

2.7. Baseline characteristics of the selected teeth

The features of the cavity type were evaluated before the placement of the restorations. This included observing and recording features such as the presence of antagonists and attrition facets, as well as relevant sociodemographic information for each patient.

2.8. Calibration procedure

The same three trained and calibrated dentists involved in the participants' selection performed the restorative procedures. For the calibration procedure step, the study director placed one restoration for each group to identify all the steps involved in the protocol. Then, all three operators placed four restorations of each group for calibration, under the supervision of the study director in a clinical setting. The restoration deficiencies were discussed with the operators before starting the study. Various details that could potentially influence the quality of the restorations, such as adhesive application, material insertion in the cavity, composite sculpture, finishing and polishing protocol, among others, were thoroughly discussed and calibrated. At this point, the operators were considered trained to perform the restorative procedures. The calibrated operators restored all teeth under the study director's supervision.

2.9. Interventions: restorative procedure

All participants received preliminary dental prophylaxis of the tooth surface with pumice and water in a rubber cup before the restorative procedure to remove any remaining dental plaque or salivary film, followed by rinsing and drying. Using a shade guide, the proper shade of the resin composite was determined. Before placing the rubber dam, the operators applied local anesthesia with a 3 % mepivacaine solution (Mepisv, Nova DFL, Rio de Janeiro, RJ, Brazil). The operators did not prepare any additional retention in the cavities.

All participants received two restorations, one from each experimental group in cavities previously selected according to the inclusion criteria. The cavity dimensions height, width, and depth in millimeters and their geometry were recorded. The cavity design was performed using only a spherical diamond bur (#1013–1017; KG Sorensen, Barueri, SP, Brazil) to remove defective restoration. The selective removal of carious tissue criteria was used for caries tissue removal, preserving the affected dentin layer [35]. The procedure involved use of hand instruments and slow-speed tungsten carbide burs (# 2 and 4; KG Sorensen). Bevels were deliberately avoided in the cavity walls to prevent unnecessary dental tissue loss. No liner or base was used.

Then, 34 % phosphoric acid (Scotchbond Universal Etchant, 3M Oral Care, St. Paul, MN, USA) was applied to dentin/enamel for 15 s, followed by rinsing with a dental syringe for 10 s. In the groups assigned for dry dentin, all dentin surfaces were completely dried for 10 s without any signs of moisture. On the other hand, in the groups assigned for moist dentin, only the excess water in the dentin surface was removed through air-drying for 2–4 s, leaving the entire dentin surface shiny (Table 2).

The Single Bond Universal adhesive (SBU; 3M Oral Care) was vigorously agitated on the entire dentin under manual pressure for 20 s, thinning with gentle air-drying for 5 s, and finally, light cured (Radii Cal, SDI, Bayswater, Victoria, Australia) for 10 s (1000 mW/cm^2). The resin composite Bulk Fill (3M Oral Care) was used in a single increment and light-cured for 30 s (1000 mW/cm^2, Radii Cal, SDI; Table 2). Occlusal adjustment and finishing were made with fine-grained diamond tips FF (KG Sorensen, Barueri, SP, Brazil) followed by polishing (Astropol, Ivoclar Vivadent, Schaan, Liechtenstein).

Table 2
Material composition, adhesive, and restorative procedures.

Material [Batch Number]	Composition (*)	Application mode	
Scotchbond Universal Etchant (3 M Oral Care, St. Paul, MN, USA), [643,399]	Orthophosphoric acid 34 %	1. Acid etchant was applied for 15 s on dentin and enamel. 2. Rinse for 10 s.	
Single Bond Universal Adhesive, (3 M Oral Care, St Paul, MN, USA), [691,954]:	Methacryloyloxydecyl dihydrogen phosphate, phosphate monomer, dimethacrylate resins, hydroxyethyl methacrylate, methacrylate-modified polyalkenoic acid copolymer, filler, ethanol, water, silane, camphorquinone	Dry Dentin 3. Air dry (10 s) to remove excess of water and keep dentin completely dry. 4. Apply the adhesive for 20 s with vigorous agitation. 5. Gently air for 5 s 6. Light cure for 10 s (1000 mW/cm^2)	Moist Dentin 3. Air dry (2–4 s) to remove only excess of water and keep dentin visible moist
Filtek Bulk Fill Posterior Restorative, (3 M Oral Care), Shades A2 and A3, [N68566]	1. Resin Matrix: AUDMA, UDMA, 1,12-dodecane-DMA (N68566) 2. Fillers: Combination of a non- agglomerated/ non-aggregated 20 nm silica filler, a non-agglomerated/ non-aggregated 4 to 11 nm zirconia filler, an aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4 to 11 nm zirconia particles) and a ytterbium trifluoride filler consisting of agglomerate 100 nm particles; 76.5 wt %, 58.4 vol%. 3. Photoinitiator: Camphorquinone	7. Single increments of 4–5 mm were placed and light-cured (1000 mW/cm^2) for 30 s in each restoration	

AUDMA: aromatic urethane dimethacrylate. UDMA: urethane dimethacrylate. 1,12-dodecane-DMA: 1,12- dedecane-dimethacrylate.

2.10. Clinical evaluation

Two experienced and calibrated examiners who were not involved in the restorative procedures evaluated according to the World Dental Federations (FDI) [36] and the modified USPHS criteria [37,38], after 6-, 12-, and 36-month clinical service.

Only the clinically relevant measures of the performance of the adhesives were evaluated (Tables 3 and 4). The main outcome was postoperative sensitivity and the secondary outcomes were fracture and retention, marginal staining, marginal adaptation, and recurrence of caries. The clinical parameters were ranked according to criteria in the following scores: FDI criteria (A – clinically very good, B – clinically good, C – clinically sufficient/satisfactory, D – clinically unsatisfactory, and E – clinically poor) [36] and USPHS criteria (Alfa – good, Bravo – satisfactory and Charlie – poor) [37,38]. Both examiners evaluated all the restorations once and independently. When there was disagreement during the evaluations, the examiners reached a consensus before dismissing the patient.

All restorations that received a clinically unsatisfactory or poor score according to FDI criteria during one recall were considered cumulative failures in the subsequent follow-up assessment. In such cases, each failed restoration was replaced with a new composite resin restoration

Table 3
Number of evaluated restorations for each experimental group classified according to the World Dental Federation (FDI).

FDI Criteria	(*)	Baseline		6 months		12 months		36 months	
		Dry Dentin	Moist Dentin	Dry Dentin	Moist Dentin	Dry Dentin	Moist Dentin	Dry Dentin	Moist Dentin
Postoperative (hyper-) sensitivity	A	45	45	36	38	36	37	37	37
	B	–	–	1	–	2	–	–	–
	C	–	–	1	–	–	1	–	–
	D	–	–	–	–	–	–	–	–
	E	–	–	–	–	–	–	–	–
Fracture and retention	A	45	45	37	36	36	35	37	35
	B	–	–	1	2	2	3	–	1
	C	–	–	–	–	–	–	–	1
	D	–	–	–	–	–	–	1	–
	E	–	–	–	–	–	–	–	1
Marginal staining	A	45	45	32	36	35	36	33	33
	B	–	–	5	1	3	2	2	2
	C	–	–	1	1	–	–	2	2
	D	–	–	–	–	–	–	–	–
	E	–	–	–	–	–	–	–	–
Marginal adaptation	A	45	45	36	38	32	30	30	29
	B	–	–	1	–	4	6	4	5
	C	–	–	1	–	2	2	3	3
	D	–	–	–	–	–	–	–	–
	E	–	–	–	–	–	–	–	–
Recurrence of caries	A	45	45	38	38	38	38	37	37
	B	–	–	–	–	–	–	–	–
	C	–	–	–	–	–	–	–	–
	D	–	–	–	–	–	–	–	–
	E	–	–	–	–	–	–	–	–

(*) A: clinically very good; B: clinically good; C: clinically sufficient/satisfactory; D: clinically unsatisfactory; E: clinically poor.

Table 4
Number of evaluated restorations for each experimental group classified according to the USPHS criteria.

USPHS Criteria	(*)	Baseline		6 months		12 months		36 months	
		Dry Dentin	Moist Dentin	Dry Dentin	Moist Dentin	Dry Dentin	Moist Dentin	Dry Dentin	Moist Dentin
Postoperative sensitivity	Alfa	45	45	37	38	38	37	37	37
	Bravo	–	–	1	–	–	1	–	–
	Charlie	–	–	–	–	–	–	–	–
Retention	Alfa	45	45	37	38	38	38	37	37
	Bravo	–	–	–	–	–	–	–	–
	Charlie	–	–	1	–	–	–	1	1
Fracture	Alfa	45	45	38	38	38	38	37	35
	Bravo	–	–	–	–	–	–	–	2
	Charlie	–	–	–	–	–	–	1	1
Marginal staining	Alfa	45	45	37	37	38	38	35	35
	Bravo	–	–	1	1	–	–	2	2
	Charlie	–	–	–	–	–	–	–	–
Marginal adaptation	Alfa	45	45	37	38	36	36	34	34
	Bravo	–	–	–	–	2	2	3	3
	Charlie	–	–	1	–	–	–	–	–
Recurrence of caries	Alfa	45	45	38	38	38	38	37	37
	Bravo	–	–	–	–	–	–	–	–
	Charlie	–	–	–	–	–	–	–	–

(*) Alfa: good; Bravo: satisfactory; Charlie: poor.

[39]. However, these newly placed restorations were not considered for further evaluation in the study. Participants whose restoration evaluations were not feasible were classified as lost to follow-up.

2.11. Statistical analysis

Descriptive statistics were used to describe the distributions of the evaluated criteria. Statistical analysis was performed for each parameter: postoperative sensitivity, fracture and retention, marginal staining, marginal adaptation, and the recurrence of caries.

For postoperative sensitivity, marginal staining, marginal adaptation, and recurrence of caries, in each overall parameter (FDI and USPHS), the differences between groups were tested by Kruskal Wallis analysis of variance rank and Mann-Whitney test ($\alpha = 0.05$) (Statistica for Windows 7.0, StatSoft Inc., Tulsa, OK, USA).

The survival rates (retention/fracture data) were calculated using the Kaplan-Meier procedure, estimating the Hazard Ratios and 95 % confidence intervals. The log-rank test was used to compare the survival distributions of these restorations ($\alpha = 0.05$). The absolute and relative risks of all approaches and the 95 % confidence interval were also calculated. Cohen's kappa statistics were used to test the inter-examiner agreement ($\alpha = 0.05$) (MedCalc Software, Version 19.1, Ostend, Belgium).

3. Results

Eighteen out of 63 subjects were not enrolled in the study because they did not fulfill the inclusion criteria (Fig. 1). Thus, a total of 45 subjects (27 female and 18 male) were enrolled in this study. The mean age of the participants was 30.0 ± 8.0 years, and their formal education

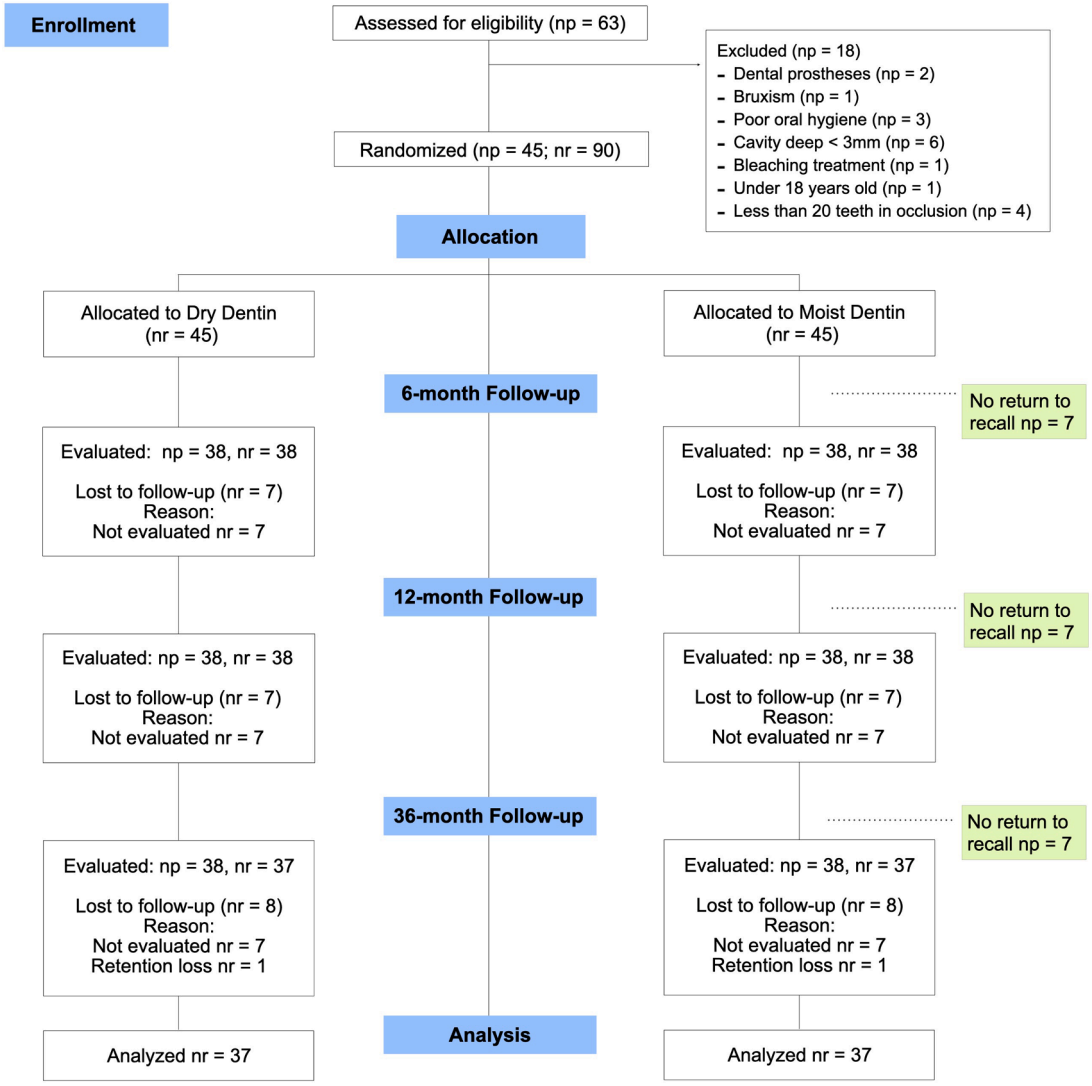

Fig. 1. Participant flow diagram in the different phases of the study design for both groups. Abbreviations: np – number of participants; nr – number of restorations.

level was high school and college formation. Ninety restorations were placed, 45 for each group. The restorative procedures were implemented exactly as planned, and no modification was performed. All baseline details relative to the research subjects and characteristics of the restored lesions are shown in Table 1. Seven subjects did not attend to recall at 6-, 12-, and 36-month evaluation, because they moved to another city or they changed their phone number, resulting in loss of contact (Fig. 1). All data regarding follow-up times are depicted in Tables 3 and 4. Only the 36-month data are described here.

3.1. Postoperative sensitivity

No restoration showed evidence of clinical issues related to postoperative sensitivity in both groups after 36 months of clinical evaluation for the FDI and USPHS criteria (Tables 3 and 4; $p > 0.05$).

3.2. Fracture and retention

After a 36-month clinical evaluation, one restoration was lost for the MD group and one for DD. The 36-month retention/fracture rates (95 % confidence interval) were 97.37 % (86.51 - 99.53) for DD and 97.37 % (86.51 - 99.53) for MD (Table 5). The Kaplan-Meier curves showed no statistical differences (Log-rank test, $p = 1.00$) among the cumulative probability of fracture and retention (Fig. 2). Table 5 depicts the paired comparisons among the two groups as the hazard ratios. The fact that 95 % CI of the Hazard Ratio crosses the null value of 1 means that none of the paired groups showed statistically significant differences.

3.3. Marginal staining

After 36 months of clinical evaluation, eight restorations presented minor marginal staining discrepancies under the FDI criteria (4 for MD, and 4 for DD; Table 3) while four restorations under the USPHS criteria (2 for MD, and 2 for DD; Table 4) with no significant differences among moist and dry dentin groups ($p > 0.05$).

3.4. Marginal adaptation

Fifteen restorations (8 for MD, and 7 for DD; Table 3) showed minor marginal discrepancies under the FDI criteria, and six restorations (3 for MD, and 3 for DD; Table 4) presented marginal discrepancies according to the USPHS criteria (Table 4). There was no significant difference between moist and dry dentin groups after 36 months of clinical evaluation ($p > 0.05$).

3.5. Recurrence of caries

No restoration showed evidence of recurrence of caries after 36

Table 1
Characteristics of the research subjects, dental arches, and cavities per group.

Distribution	Number of participants	
Gender		
Female	27	
Male	18	
Age distribution		
20–29	29	
30–39	10	
40–49	4	
>49	2	
Characteristics of cavities and arch distribution	Number of research subjects	
Presence of antagonist	Dry Dentin	Moist Dentin
Yes	44	45
No	1	0
Attrition facet		
Yes	3	3
No	42	42
Arch distribution		
Maxillary	19	20
Mandibular	26	25
Cavity depth		
3 mm	16	14
4 mm	21	21
>4 mm	8	10
Black classification		
I	37	38
II	8	7
Number of restored surfaces		
1	35	38
2	10	7
3	0	0
4	0	0
Reason for restoration		
Marginal Fracture	1	0
Esthetic Reasons	18	17
Marginal Discoloration	0	0
Bulk Fracture	7	8
Primary/Secondary caries	19	20

Table 5
Absolut risk (95 % CI), relative risk (95 % CI), and hazard ratio (95 % CI) for outcome fracture and retention for the two groups after 36 months of clinical evaluation.

	Absolute risk (95 % CI)	Relative risk (95 % CI)*	Hazard ratio (95 % CI)*
Dry dentin	97.37 (86.5 – 99.5)	1.00 (0.06 - 15.41)	1.00 (0.55 to 1.81)
Moist dentin	97.37 (86.5 – 99.5)		

* Related to moist dentin.

months of clinical evaluation for both groups according to the FDI and USPHS criteria (Tables 3 and 4; $p > 0.05$).

4. Discussion

Maintaining moisture in demineralized dentin during the adhesive protocol has been widely endorsed by manufacturers and implemented as a common clinical practice. However, this recommendation lacks substantial high-level evidence for validation [40], mainly due to limited clinical trials. Notably, composite restorations in non-carious cervical lesions (NCCLs) [16,17] and posterior teeth [18] using etch-and-rinse adhesives, have demonstrated satisfactory clinical performance regardless of dentin moisture levels, following 18–24 and 36 months of clinical evaluation, respectively. Interestingly, similar clinical outcomes have been observed with universal adhesives after 36 months of clinical evaluation in NCCLs [21,22]. To the best of the author's knowledge, this study represents the first 36 months of clinical trial demonstrating that dentin moisture level does not significantly influence the clinical performance of a universal adhesive in posterior restorations. Consequently, both the first and second null hypotheses were accepted.

Various factors may contribute to these findings, including the characteristics of the adhesive system and the composite material and technique employed. The similar clinical behavior between moist and dry dentin could be related to the composition of the universal adhesive used. SBU contains a polyalkenoic acid copolymer that chemically bonds to the calcium in hydroxyapatite [41], providing strong bonding performance and moisture stability by the hydrogen bonds with water absorbed on the hydroxyapatite [4,42]. Additionally, the inclusion of 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) in SBU plays an important role in chemical bonding to calcium salts of hydroxyapatite. The 10-MDP monomer is absorbed into hydroxyapatite in a regularly layered structure, resulting in an adhesive interface with higher resistance to degradation [43]. The chemical bonding facilitated with both compounds suggests that SBU can yield satisfactory clinical results concerning marginal staining and marginal adaptation, regardless of the dentin moisture conditions [18,24].

Another crucial aspect of SBU composition is its increased water content (ranging from 10 to 15 % by weight) [44] which is important for the ionization of the acidic functional monomer and enabling self-etch bonding [4]. While the presence of water could potentially pose challenges, especially when applied to moist dentin, probably leading to an excess of water at the hybrid layer and subsequent hydrolytic degradation of the interface [7], the similar clinical performance over moist and dry dentin suggests that SBU should present a proper water content in its composition. This ensures adequate wetting of the dentin surface, preventing the collapse of collagen fibrils [20], and allowing resin monomers' infiltration, thereby promoting effective micromechanical interlocking and hybrid layer formation [14].

Furthermore, the active application technique could improve this scenario. Through the rubbing motion on dentin, the resin monomers would be compressed and drawn into the demineralized collagen network, thus reducing the presence of air voids responsible for stimulating the pulpal complex and causing sharp pain [8], thus reducing the subsequent risk of postoperatory sensitivity, regardless of dentin moisture [18,24], as observed in this study. In addition, not only can monomer infiltration be enhanced, but also the chemical bonding between functional monomers and the hydroxyapatite of internal dentinal tubules [45], improving the formation of calcium-salt nanolayers from hydroxyapatite [46], as well as with the peritubular dentin and collagen fibers preserved due to the surface moisture of the deep dentin [47]. The active application could also facilitate solvent removal and reduce residual water that could compromise the degree of monomer conversion, resulting in enhanced physical and mechanical properties of the hybrid layer [11,48], making it more resistant to degradation and leading to minimal marginal defects over time.

It is known that keeping moist dentin and dry enamel simultaneously is challenging. Considering that in the wet group, only 2–4 s were applied to remove excess water and maintain visible moisture on the dentin, it is reasonable to assume that after air-drying in the 'wet dentin group,' there might be minimal residual moisture present in the etched enamel.

Indeed, it's well-known that even a small amount of water retained within the enamel prisms has the potential to hinder proper monomer infiltration, thereby affecting bonding performance [12,49], which is pivotal for ensuring effective sealing and marginal integrity for the old generations of simplified etch-and-rinse adhesives [2]. However, no significant impact on the durability of bonding to enamel was observed when universal adhesives were applied in the etch-and-rinse mode to wet or dry enamel [12,13]. Nevertheless, this challenge appears to be mitigated, as the active application of the adhesive on enamel can enhance solvent evaporation, improving the conditioning pattern and resulting in superior adhesive infiltration [50]. Additionally, the active application stimulates more chemical reactions of functional monomers,

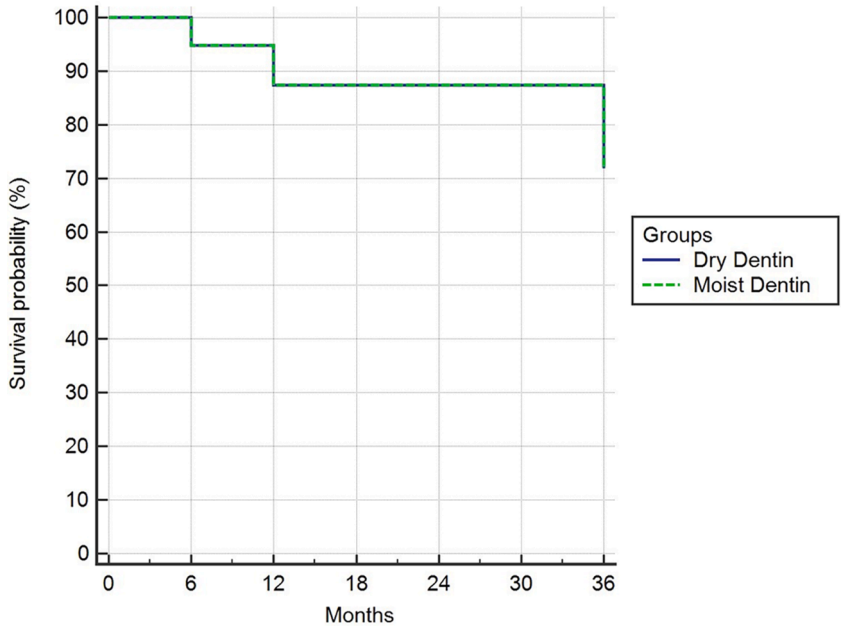

Fig. 2. Survival curves for both groups.

such as 10-MDP, with enamel [51]. All these in vitro studies support the idea that there are no significant differences between both groups in terms of marginal discrepancies (such as marginal staining and marginal adaptation), as observed in the results of the present study and in agreement with previous research [18,24,33].

It is worth mentioning that the prior phosphoric acid etching step could also improve the bonding performance on enamel by creating microporosities that allow the adhesive micromechanical interlocking [4]. This effect of the 10-MDP of SBU associated with the enamel etching can be observed in the minimal discrepancies in marginal integrity of the posterior restorations of the current 36-month clinical trial. This study showed 1.5 % marginal staining defects for both dentin moisture conditions; and 3.0 % marginal adaptation defects in moist dentin, and 2.6 % in dry dentin. These findings are slightly minor compared to the other 36 months of clinical evaluation in posterior restorations performed with the predecessor adhesive system of SBU, the Adper Single Bond 2, a 10-MDP free adhesive, which showed 3.5 % for marginal staining and 3.8 % for marginal adaptation defects, regardless of the dentin moisture [18]. However, it is worth mentioning that all of these discrepancies were classified as clinically acceptable and were not considered failures. Instead, they only required monitoring or refurbishment [36].

No difference in fracture and retention rate was expected after 36 months due to the characteristics of the restorative material used. Bulk-fill composites exhibit higher translucency and incorporate more reactive photoinitiators, enabling placement in thick increments of 4–5 mm and ensuring uniform polymerization and degree of conversion [52]. These factors are essential to achieving satisfactory mechanical properties that enhance the longevity of restorations [53]. Consequently, the combination of universal adhesives with bulk-fill resin composites has proven to be a promising and successful restorative technique, with a fracture rate of 92.2 % – 100 % after two [54,55] and three years of follow-up [56,57], which is compared to the 97.4 % fracture rate found in this study. Additionally, the optimal degree of conversion and depth of cure achieved allows bulk-fill composites to exhibit reduced polymerization shrinkage stress [58], thereby decreasing the incidence of postoperative sensitivity [59], as observed in this study and other short- [24,34,54,60,61], mid- [18,56,62], and long-term clinical trials [63,64].

While the current study yields promising results, it is important to mention some limitations. Primarily, this was a 36-month clinical study. Given that fractures and secondary caries, major reasons for the failure of composite restorations, typically manifest after extended clinical service periods [2], it is imperative to conduct future studies with long-term follow-ups to confirm the study's hypothesis. Secondly, only one universal adhesive was evaluated in this study. Therefore, these results may be carefully interpreted for other universal adhesives, considering that most of them present different chemical compositions. In the present study, to mitigate the possibility of confounding factors, only low-risk patients were included. However, considering the higher risk of failure of posterior restorations in high caries risk patients [3,65], future clinical studies should be conducted to evaluate the effect of dentin moisture in participants with high-risk caries. Finally, more than 80 % of the restorations in the present study were Class I restorations. Considering that Class II restorations with regular viscosity composites showed a higher risk of failure compared to Class I restorations [65], future studies should be conducted on the clinical performance of bulk-fill composites in cavities with elevated complexity.

5. Conclusion

The clinical performance of a universal adhesive when applied in etch-and-rinse mode was not influenced by dentin moisture in posterior bulk-fill composite restorations after 36 months.

CRediT authorship contribution statement

Romina Ñaupari-Villasante: Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Camila Falconi-Páez:** Writing – original draft, Investigation, Conceptualization. **Andrea S. Castro:** Writing – original draft, Validation, Investigation, Conceptualization. **Mario F. Gutiérrez:** Writing – original draft, Supervision, Investigation, Conceptualization. **Maria L. Mendez-Bauer:** Writing – original draft, Supervision, Investigation, Conceptualization. **Paulina Aliaga:** Visualization, Funding acquisition, Data curation, Conceptualization. **Andrés Dávila-Sánchez:** Writing – original draft, Project administration, Formal analysis, Conceptualization. **Cesar Arrais:** Writing – original draft, Supervision, Conceptualization. **A Reis:** Writing – review & editing, Writing – original draft, Project administration, Conceptualization. **Alessandro D. Loguercio:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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