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ORIGINAL ARTICLE

Thirty-six-month clinical evaluation of different adhesive strategies of a universal adhesive

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Abstract

Aim The aim of this clinical trial was to evaluate and compare the performance of a universal adhesive with different adhesive strategies in the restoration of non-carious cervical lesions (NCCLs) over a 36-month period.

Material and method One hundred sixty-five NCCLs in 35 patients (13 female, 22 male) with at least 3 lesions each were included in this study. Three groups were formed according to the adhesive strategy used ($n = 55$): selective-etch mode, etch-and-rinse mode, or self-etch mode of a universal adhesive, Single Bond Universal. The same nanofilled resin composite, Filtek Ultimate, was used for all restorations by a single operator. The restorations were evaluated by two calibrated examiners at baseline and at 6, 12, 18, 24, and 36 months in accordance with the modified USPHS criteria. The chi-square test was used for intergroup comparison and Cochran's Q test for intragroup comparison ($\propto = 5\%$).

Results At 36 months, the recall rate was 98.1% and three restorations, one from each group, had failed because of retention loss ($P > 0.05$). The self-etch mode group showed 17 bravo scores for both marginal staining and marginal adaptation after 3 years, which was significantly different from the selective-etch and etch-and-rinse groups ($P < 0.05$). For all groups, the only statistically significant difference was found when baseline and 36-month evaluations were compared in terms of marginal staining ($P = 0.000$). When the marginal adaptation values at 36 months were compared with those at the baseline, statistically significant differences were found in the etch-and-rinse and self-etch mode groups ($P < 0.05$). Neither secondary caries nor postoperative sensitivity was observed at any recall.

Conclusion All adhesive modes showed similar retention rates. Although all restorations were clinically acceptable, restorations in self-etch mode showed less satisfying performance for marginal staining and marginal adaptation.

Clinical relevance At the end of 36 months, the Single Bond Universal adhesive received acceptable scores according to the modified United States Public Health Service (USPHS) criteria. However, clinicians should be aware that its use in self-etch application mode tends to result in marginal staining and marginal deterioration when compared with etch-and-rinse and selective-etch application modes.

Keywords Etch-and-rinse · Self-etch · Selective-etch · Universal adhesives · Non-carious cervical lesions

Introduction

The incidence of non-carious cervical lesions (NCCLs) has increased with prolonged human life and improved oral hygiene habits [1]. Most patients are not aware of these lesions until they have tooth hypersensitivity. Restoration with resin-based composites of these lesions may become necessary if pulp vitality is affected or plaque retention increases. Adhesion is more difficult due to a degree of sclerosis and the formation of a hybrid layer on NCCLs [2]. Moreover, during restorative treatment, the proximity of the lesion to the gingival tissue may adversely affect clinical success. Adhesion to both enamel and dentine can be achieved using etch-and-rinse and self-etch adhesive strategies.

Etch-and-rinse adhesive systems still provide the best achievable bond to the enamel [3, 4]. Due to the fact that the technique was considered highly sensitive, self-etch systems were introduced to simplify the clinical procedure as well as to control the sensitivity to humidity of the etch-and-rinse technique. Studies comparing the performance of self-etch and etch-and-rinse adhesives reported that the latter

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show higher performance in terms of marginal integrity under clinical conditions [5, 6]. One of the main challenges that clinicians encounter is self-etch adhesives' inability to etch enamel, unlike phosphoric acid, which is likely responsible for the higher rates of marginal discoloration of cervical restorations [7].

New adhesive systems are continuously being manufactured for long-lasting restorations. Recently, adhesive systems that can be used in "etch-and-rinse," "self-etch," and "selective-etch" modes, called "universal adhesives," have been developed. The pH value of universal adhesives varies within a mild range, which makes them a good choice for adhesion to dentine but possibly insufficient for enamel bonding. Numerous in vitro studies evaluating the adhesive performance of universal adhesives have been conducted [8–12]. Some of these studies suggested that the etching phase for dentin did not make any difference while others reported that the etch-and-rinse technique had a positive effect on bonding to enamel. Moreover, some in vitro studies showed that selective enamel etching improved the enamel bonding performance before the application of self-etch adhesives [13, 14]. In an 8-year clinical evaluation conducted by Peumans et al. [15], selective etching resulted in only some minor positive changes in terms of marginal adaptation and staining on enamel. Another important factor to be taken into account is the 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) found in some universal adhesives. Its ability to interact with calcium in hydroxyapatite may provide higher bond strength to dental substrate [16, 17]. In an in vitro study, the authors reported that universal adhesives containing MDP exhibited higher bond strength and lower microleakage [18]. Although there are many in vitro studies evaluating universal adhesives' mechanical and physical properties, real performances need to be confirmed by clinical trials.

To the best of the authors' knowledge, there are limited clinical data about the performance of universal adhesives in non-carious cervical restorations. The purpose of this clinical trial was to evaluate and compare the performance of a universal adhesive with different adhesive strategies in the restoration of non-carious cervical lesions (NCCLs) over a 36-month period. The tested null hypothesis was that there would be no difference among the performances of different adhesive strategies of the tested universal adhesive on cervical restorations.

Material and method

This study was reported in accordance with the CONSORT statement [19]. The study protocol was approved by the Local Human Ethics Committee of Hacettepe University (protocol no: KA-17088) and all patients were informed and signed a written consent form prior to the study.

The inclusion criteria for patients were as follows: over 18 years old, good general health, good oral hygiene, available for recall, at least 20 teeth under occlusion, and the presence of at least three NCCLs. The subjects that had systemic or local disorders preventing the application of treatment, poor oral hygiene, bruxism habits, or severe or chronic periodontitis were excluded. If the teeth selected for study were non-vital or had any restorations on other surfaces, they were not included.

Thirty-five out of 74 subjects ranging in age from 27 to 81 years met the eligibility criteria and participated in the study (Fig. 1). Using a power of 80%, the sample calculation indicated the need for approximately 50 restorations for each group in order to determine a difference of 25% among the study groups. Before the treatment procedure, the depths of lesions were classified by periodontal probe according to Smith and Knight's Tooth Wear Index [20]. The teeth with scores of 3 (cervical defect less than 1–2 mm deep) and 4 (cervical defect more than 2 mm deep) were included in the study. The amount of enamel margins, preoperative sensitivity, and gingival condition were recorded. Air was applied for 10 s using an air syringe placed 1 cm away from the tooth surface for evaluating preoperative sensitivity. The adjacent teeth were covered with cotton rolls in order to protect them from the effects of the applied air. The cavo-surface margin could not contain more that 50% of the enamel [21].

All patients received a dental screening and were informed about oral care before the operative treatment. Before the restorative procedure, the selected teeth were cleaned with pumice and water in a rubber cup, followed by rinsing with water. After shade selection with a Vita shade guide, the occlusal margins of lesions were prepared with a 0.5-mm bevel using a high-speed handpiece with flame-shaped diamond burs (Diatech, Heerbrugg, Switzerland). None of the patients required anesthesia. The isolation was performed with cotton rolls and suction.

The selected teeth were allocated into three groups to be restored according to the adhesive strategies for a universal adhesive, Single Bond Universal (SU) (3M ESPE, St. Paul, MN, USA), as follows: (1) (SU), selective-etch mode ($n = 55$); (2) SU, etch-and-rinse mode ($n = 55$); and (3) SU, self-etch mode ($n = 55$). The teeth were assigned to the groups randomly on the day of the restorative procedure using a table of random numbers.

The adhesion protocols were performed according to the manufacturer's directions as described in Table 1. After the application of adhesive, a nanofilled resin composite, Filtek Ultimate (3M ESPE), was applied incrementally, not greater than 2 mm. A LED-curing unit (Starlight, Mectron, Carasco, Italy) was used in all light-curing procedures. Intensity of 1400 mW/cm^2 was checked following each operation with a curing radiometer (Demetron, Danbury, CT, USA). The restorations were finished with a high-speed handpiece under

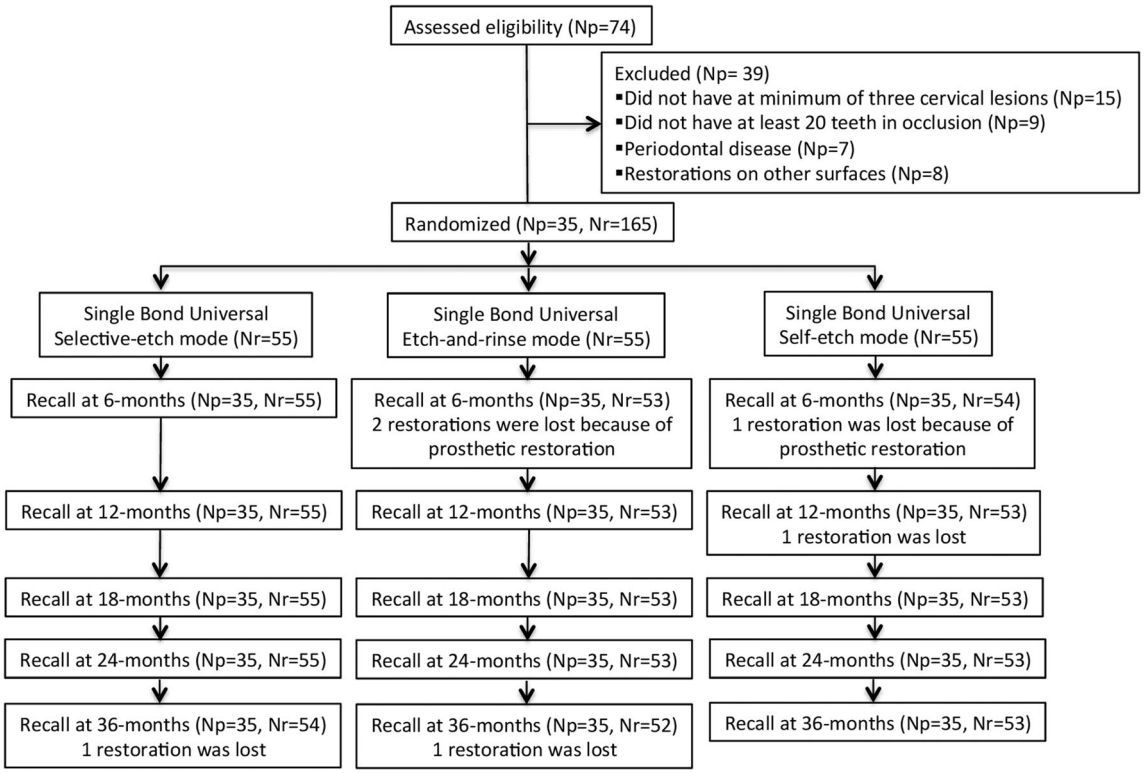

Fig. 1 Flow diagram. Np, number of patients; Nr, number of restorations

an air/water spray using fine and extrafine diamond finishing burs (Diatech Dental AC). Subsequently, polishing discs (Soflex, 3M ESPE) and rubber points (Kerr) were used for polishing. The clinical procedure for the restorations was performed by a single operator (C.A.). All details regarding the distribution of NCCLs and the characteristics of subjects and lesions are presented in Table 2.

Two experienced and calibrated evaluators (G.O. and A.R.Y.) assessed the restorations. Intraexaminer and

Table 1 Materials used in the study

Adhesive/batch	Composition	Application technique[a]		
Scotchbond Universal Etchant (3M ESPE, St. Paul, MN, USA) (524441)	30–40% phosphoric acid, synthetic amorphous silica (fumed), polyethylene glycol, aluminum oxide, water	1. Apply etchant for 15 s. 2. Rinse for 10 s. 3. Air-dry for 5 s.		
Single Bond Universal (3M ESPE, St. Paul, MN, USA) (527687)	MDP phosphate monomers, dimethacrylate resins, HEMA, methacrylate-modified polyalkenoic acid copolymer, fillers, ethanol, water, initiators, silane	Self-etch 1. Apply adhesive with a microbrush with rubbing motion for 20 s. 2. Evaporate solvents with gentle stream of air until adhesive. movement no longer can be noticed 3. Light cure for 10 s.	Etch-and-rinse 1. Apply etchant. 2. Apply adhesive as detailed in self-etch technique.	Selective etch 1. Apply etchant selectively on enamel. 2. Apply adhesive as detailed in self-etch technique (both enamel and dentine).
Filtek Ultimate (3M ESPE, St. Paul, MN, USA) (N214468)	Bis-GMA, UDMA, TEGDMA, bis-EMA, PEGDMA, silica filler, zirconia filler	Apply incrementally in 2-mm thickness.		

MDP, methacyloyloxydecyl dihydrogen phosphate; *HEMA*, 2-hydoxyethyl methacrylate; *Bis-GMA*, bisphenol A glycol dimethacrylate; *UDMA*, urethane dimethacrylate; *TEGDMA*, triethyleneglycol dimethacrylate; *bis-EMA*, bisphenol A ethoxylate dimethacrylate; *PEGDMA*, polyethylene glycol dimethacrylate

[a] According to the manufacturer's instructions

Table 2 Distribution of NCCLs and characteristics of subjects and lesions

Characteristics of subjects and lesions	Number of lesions		
Subjects			
Age distribution (years)			
20–29	6		
30–39	6		
40–49	51		
50–59	48		
> 60	54		
	Selective-etch	Etch-and-rinse	Self-etch
Degree of wear			
Scores			
3	37	35	36
4	18	20	19
Tooth distribution			
Anterior			
Incisor	7	8	10
Canine	13	12	13
Posterior			
Premolar	32	30	25
Molar	3	5	7
Arc distribution			
Maxilla	32	32	36
Mandibula	23	23	19
Preoperative sensitivity			
Yes	27	30	26
No	28	25	29

interexaminer agreement of at least 85% was achieved before the evaluations. For the calibration process, the evaluators observed 20 patients with 35 restorations of each score for each criterion. At the same time, digital images were taken and all criteria were assessed on the photographs. Each restoration was evaluated at baseline and 6, 12, 18, 24, and 36 months. The restorations were checked for retention, marginal staining, marginal adaptation, secondary caries, and postoperative sensitivity according to the modified United States Public Health Service "USPHS" criteria [22] (Table 3). All data during the evaluations were recorded on a case report form that was not shown to the evaluators after each observation; therefore, they were blinded to the distribution of groups during follow-up recalls. All findings were recorded as alpha at baseline. The restorations were evaluated using an intraoral mirror and dental probe under adequate light. Digital images were also taken at baseline and at each recall to document the performance of the restorations. Disagreements were discussed until consensus was reached. The subjects were also asked whether they had sensitivity to stimuli or hot/cold. One week after the restorative procedure, postoperative sensitivity was assessed by the same procedure as was done for the preoperative sensitivity.

Table 3 Modified USPHS evaluation criteria [22]

Evaluation criteria	Rating scale
Retention	Alpha: Retained Charlie: Mobile or missing; clinically unacceptable
Marginal discoloration	Alpha: No discoloration at margins Bravo: Shallow discoloration (localized or generalized); clinically acceptable Charlie: Deep discoloration (localized or generalized); clinically unacceptable
Marginal adaptation	Alpha: Undetectable Bravo: Visible evidence of a crevice along the margin, dentin not exposed, clinically acceptable Charlie: Explorer penetrates into crevice, dentin is exposed; clinically unacceptable
Secondary caries	Alpha: Absent Charlie: Present; clinically unacceptable
Post-op sensitivity	Alpha: Absent Charlie: Present; clinically unacceptable

Statistical analysis

All data were analyzed at a significance level of 0.05 using SPSS version 22.0 (IBM, Chicago, IL, USA). Descriptive statistics were used to describe the distributions of the evaluated criteria. The distribution of restorations according to teeth, arc, and degree of wear was evaluated by chi-square test. The adhesive strategy groups for all evaluation criteria were also compared by chi-square test. The changes across different time points within each application mode were analyzed by Cochran's Q test followed by McNemar's test. Cohen's kappa statistic was used to examine interexaminer agreement.

Results

A total of 165 restorations were placed in 35 patients (22 males and 13 females) with a mean age of 54.5. In terms of distribution of teeth, arc, and degree of wear, no significant difference was seen among the groups ($P > 0.05$). Table 4 shows the results of the clinical evaluation of the restorations. Strong agreement between the evaluators with a kappa value of 0.96 was found. Recall rates were 100% for all follow-ups. At 6 months, 3 restorations could not be evaluated due to prosthetic restorations (2 from etch-and rinse mode and 1 from self-etch mode). Three restorations (one from self-etch at 6 months, one from selective-etch at 36 months, and one from etch-and-rinse at 36 months) were lost ($P > 0.05$). At the end

Table 4 Clinical evaluation outcomes of different application modes of SU

Evaluation criteria	Score	6 months			12 months			18 months			24 months			36 months		
		Se-etch ($n=55$) (%)	ER ($n=53$) (%)	SE ($n=54$) (%)	Se-etch ($n=55$) (%)	ER ($n=53$) (%)	SE ($n=54$) (%)	Se-etch ($n=55$) (%)	ER ($n=53$) (%)	SE ($n=54$) (%)	Se-etch ($n=55$) (%)	ER ($n=53$) (%)	SE ($n=53$) (%)	Se-etch ($n=55$) (%)	ER ($n=53$) (%)	SE ($n=53$) (%)
Retention	A	55 (100)	53 (100)	54 (100)	55 (100)	53 (100)	53 (98.1)	55 (100)	53 (100)	53 (100)	55 (100)	53 (100)	53 (100)	54 (98.2)	52 (98.1)	53 (100)
	C	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1.9)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1.8)	1 (1.9)	0 (0)
Marginal staining	A	55 (100)	51 (96.2)	52 (96.3)	53 (96.4)	51 (96.2)	49 (92.5)	53 (96.4)	51 (96.2)	49 (92.5)	52 (94.5)	48 (90.6)	43 (81.1)	47 (87.0)	45 (86.5)	36 (67.9)
	B	0 (0)	2 (3.8)	2 (3.7)	2 (3.6)	2 (3.8)	4 (7.5)	2 (3.6)	2 (3.8)	4 (7.5)	3 (5.5)	5 (9.4)	10 (18.9)	7 (13.0)	7 (13.5)	17 (32.1)
	C	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 adaptation	A	55 (100)	51 (96.2)	50 (92.6)	55 (100)	51 (96.2)	47 (88.7)	55 (100)	51 (96.2)	47 (88.7)	54 (98.2)	50 (94.3)	41 (77.4)	53 (98.1)	47 (90.4)	36 (67.9)
	B	0 (0)	2 (3.8)	4 (7.4)	0 (0)	2 (3.8)	6 (11.3)	0 (0)	2 (3.8)	6 (11.3)	1 (1.8)	3 (5.7)	12 (22.6)	1 (1.9)	5 (9.6)	17 (32.1)
	C	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	A	55 (100)	53 (100)	54 (100)	55 (100)	53 (100)	53 (98.1)	55 (100)	53 (100)	53 (100)	55 (100)	53 (100)	53 (100)	54 (98.2)	52 (98.1)	53 (100)
	B	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)
	C	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)
Postop-sensitivity	A	55 (100)	53 (100)	54 (100)	55 (100)	53 (100)	53 (98.1)	55 (100)	53 (100)	53 (100)	55 (100)	53 (100)	53 (100)	54 (98.2)	52 (98.1)	53 (100)
	B	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)
	C	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)

of 36 months, 159 restorations were evaluated in 35 patients and the dropout rates for 6, 12, 18, 24, and 36 months were 1.8%, 2.4%, 2.4%, 2.4%, and 3.6%, respectively. The overall retention rate was 98.1%.

For marginal staining, two (3.8%) restorations from the etch-and-rinse group and two (3.7%) from the self-etch group were scored as bravo at the 6-month recall ($P = 0.185$). None of the restorations in the selective-etch group showed marginal staining until the 12-month examinations. At the 12-month recall, 2 restorations from the selective-etch group, 2 from the etch-and-rinse group, and 4 from the self-etch group were rated as bravo, which was not different from the 18-month evaluation. Eighteen restorations (3 from selective-etch, 5 from etch-and-rinse, and 10 from self-etch) showed slight marginal staining at the 24-month recall. No statistically significant differences were observed among the groups in terms of marginal staining at 12, 18, or 24 months ($P = 0.592$, $P = 0.592$, $P = 0.077$, respectively). At the end of 36 months, marginal staining was observed in 17 restorations, all of which were in the self-etch mode group, which was significantly different from the selective-etch and etch-and-rinse groups ($P < 0.05$). For all groups, the only statistically significant difference was seen when the baseline and 36-month evaluations were compared ($P = 0.000$).

In terms of marginal adaptation, no significant difference was recorded among the groups at the 6-month recall ($P = 0.056$). From the 12-month evaluation, significant differences were found among the groups at 18-, 24-, and 36-month recalls. Two (3.8%) restorations from the etch-and-rinse group and six (11.3%) from the self-etch group showed bravo scores for marginal adaptation at 12 months ($P = 0.010$). The number of bravo scores recorded for all groups did not change at 18 months ($P = 0.010$). In the selective-etch group, no deterioration in marginal adaptation was observed until the 24-month evaluation. The self-etch group showed significantly worse marginal adaptation at 24- and 36-month recalls ($P = 0.001$ and $P = 0.000$, respectively). At the end of 36 months, one (1.9%) restoration from the selective-etch group, five (9.6%) from the etch-and-rinse group, and seventeen (32.1%) from the self-etch group were rated as bravo ($P = 0.000$). When marginal adaptation values at 36 months were compared with those at the baseline, statistically significant differences were found ($P < 0.05$), except for the selective-etch group ($P = 0.416$).

None of the restorations showed secondary caries or postoperative sensitivity at any recall. Representative images of restorations at each recall are presented in Figs. 2, 3, and 4.

Discussion

In the present study, the different application strategies for universal adhesives affected the 3-year clinical performance of the non-carious cervical restorations significantly. Thus, the null hypothesis that there would be no difference among the restorations when universal adhesive was applied in "etch-and-rinse," "self-etch," or "selective-etch" application mode has to be rejected. It is well-known that a rubber dam is an important barrier in preventing moisture contamination during the placement of direct restorations. However, two meta-analyses investigating the clinical performance of direct posterior restorations [23, 24] revealed that the type of isolation did not affect the survival rate of restorations. Loguergio et al. [25] evaluated the influence of isolation method in NCCLs and found that the use of cotton rolls or a rubber dam was similar in terms of retention rates of adhesive restorations. Therefore, the authors in the present study used cotton rolls and suction for isolation. It was also taken into consideration that the distributions of lesions were in different quadrants, which could prolong chairside time.

In the present study, the age range was not restricted and the ages of individuals ranged from 20 to 81 years. It is known that sclerotic dentin formed with increasing age of individuals may affect adhesion [26]. Ritter et al. [27] evaluated the clinical performance of an all-in-one adhesive in NCCLs with different degrees of dentin sclerosis. They reported that 13% of the restorations placed in teeth with significant sclerosis were not retained. One of the limitations of the present study was the lack of classification of sclerotic dentin. On the other hand, at 36 months, only 3 restorations (one from each group) had failed due to loss of retention. In the present study, all adhesive procedures were performed using the method called "active application" so that SU adhesive was agitated on the surfaces of teeth for 20 s. Some in vitro studies have reported that agitation of self-etch adhesives was able to improve bonding to enamel and dentine [28–30]. This application may produce more effective demineralization and promote a better interaction with the smear layer and dentine. In our study, all adhesive strategies showed higher retention rates. These successful results obtained might have been related to the rubbing of adhesive. This was also consistent with the clinical trials conducted by Zander-Grande et al. [31] and Loguercio et al. [32], who reported that rubbing motion improved the retention rates.

Another reason for the high retention rate (98.1%) could be the beveling procedure. In the present study, all preparations were performed with a 0.5-mm bevel. Some studies have shown that beveling can reduce marginal microleakage [33], improve marginal adaptation [34], and result in better adhesion [35]. However, these positive features can prevent the adhesive materials from showing their actual performance. On the other hand, our results showed that failure of marginal adaptation in self-etch mode was increasingly seen in the following period. It might be concluded that the positive characteristic of beveling, which increases marginal adaptation, was not effective in the self-etch group. In an 18-month clinical

Fig. 2 A cervical restoration of alpha score from all criteria (left to right): preoperative, baseline, 12, 24, and 36 months

study conducted by Perdigao et al. [36], the effects of enamel beveling and enamel etching were evaluated separately and together for a self-etching adhesive and it was found that the 18-month survival rate was not improved by enamel beveling or enamel etching. When compared with the baseline, all procedures revealed significant deteriorations still within clinically acceptable range at 18 months for overall marginal staining and marginal adaptation. In another clinical study, Baratieri et al. stated that enamel beveling did not improve retention after a 3-year period [37].

In a meta-analysis, different adhesive systems were evaluated for cervical restorations and one-step self-etch adhesives showed inferior clinical performance compared with other adhesive systems [38]. Kearns et al. noted that mild one-step self-etch adhesives performed better than strong ones [39]. Single Bond Universal (SU) is a mild adhesive with pH 2.7 that may cause the enamel not to be sufficiently etched. Loguercio et al. investigated the effect of SU adhesive's different adhesive strategies and found that the bonding strategy had no significant influence on the clinical performance of cervical restorations [40]. In a recent 2-year follow-up study, etch-and-rinse (Adper Single Bond 2), self-etch (Clearfil SE Bond), and universal adhesive (Scotchbond Universal) systems were compared for the restoration of NCCLs and no statistically significant differences were observed among the groups [41]. Moreover, SU showed similar clinical performances in the two adhesive strategies (etch-and-rinse and self-etch). On the other hand, inadequate enamel etching was shown to be the cause of marginal staining and deterioration in marginal adaptation [42]. In our study, bravo scores for marginal staining and marginal adaptation increased significantly when comparing the baseline and 36-month evaluations for all groups. Moreover, SU adhesive's self-etch mode showed inferior performance with regard to marginal staining and adaptation. Our findings are in agreement with a study by Lawson et al. that compared the clinical performance of a two-bottle total-etch adhesive and SU adhesive's self- and total-etch modes for cervical restorations. They found that self-etch mode had a less satisfying performance in terms of marginal staining than total-etch mode [5]. Another study compared two universal adhesive systems (Scotchbond Universal and Prime&Bond Elect) and reported that SU adhesive applied in self-etch mode demonstrated a high level of marginal staining when compared with the other groups [43].

In a 1-year in vitro study conducted by Marchesi et al., the adhesive performance of a multi-mode adhesive with different bonding strategies was evaluated [9]. They reported that the self-etch system showed higher bond strength over time and suggested that this may have been due to deeper decalcification (up to 3–6 μm) of human dentin by phosphoric acid. Some in vitro studies also found that only the etching of the enamel increased the bond strength for mild self-etch adhesives [44–46]. Improved bond strength might be attributed to dentinal collagen that has become very vulnerable to enzymatic and hydrolytic degradation after the total-etch procedure as shown in these studies. Moreover, Van Meerbeck et al.

Fig. 3 A cervical restoration of bravo score from marginal adaptation (left to right): preoperative, baseline, 12, 24, and 36 months

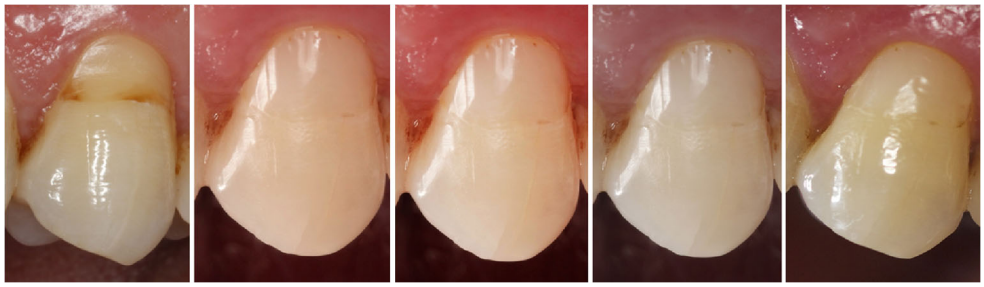

Fig. 4 A cervical restoration of bravo score from marginal staining (left to right): preoperative, baseline, 12, 24, and 36 months

recommended selective etching of the enamel margins followed by application of a mild self-etch adhesive [47]. In our study, selective etching performed well in terms of marginal adaptation with only one bravo score, but it was not significantly different from the etch-and-rinse procedure. Both etch-and-rinse and selective etch modes showed improved marginal adaptation when compared with the self-etch mode.

SU adhesive contains a co-monomer called HEMA, performing as a wetting agent. The adhesive layer is hydrophilic as a result of HEMA making it difficult to remove water from the adhesive. Tay et al. found that permeability to water accelerated the rate of water sorption, which challenged the durability of bonding [48]. The MDP monomer component of Single Bond Universal makes this adhesive more hydrophobic compared with previous simplified adhesives. It is known that MDP interacts chemically with hydroxyapatite and forms a durable nanolayer at the adhesive interface [17]. In a study conducted by Zhang et al. [49], the effect of MDP on short- and long-term enamel bond strength was evaluated. They reported that additional chemical bonding of MDP with hydroxyapatite at the etched enamel could significantly increase the enamel bond strength. This is supported by our findings showing a better performance obtained in groups where the enamel surfaces were etched. Moreover, the presence of Vitrebond copolymer improves adhesives' wetting capability by rehydration of dentin collagen, which results in an improved hybrid layer. Additionally, the higher retention rates for all groups might be attributed to MDP monomer and Vitrebond copolymer in SU adhesive.

In accordance with some previous studies [6, 50, 51], thirty-one restorations for marginal staining and twenty-three restorations for marginal adaptation were classified as bravo when no secondary caries were observed at the end of 36 months. In the present study, the restorations were observed for only a short length of time. Further evaluations are planned to compare the long-term performance of different adhesive strategies of the tested universal adhesive.

Conclusion

Within the limitations of this study, all adhesive modes showed similar retention rates. At the end of 36 months, Single Bond Universal adhesive received acceptable scores according to the modified USPHS criteria. Although all restorations were clinically acceptable, those in self-etch mode showed less satisfying performance in terms of marginal staining and marginal adaptation.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included this study.

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