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ORIGINAL ARTICLE

A 13-year clinical evaluation of two three-step etch-and-rinse adhesives in non-carious class-V lesions

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Abstract This 13-year randomized clinical trial compared the clinical effectiveness of two three-step etch-and-rinse adhesives in combination with a hybrid, stiffer composite versus a micro-filled, more flexible composite. The influence of composite stiffness on the clinical performance of one of the adhesives was assessed as well. One hundred and forty-two non-carious cervical lesions were restored with composites with contrasting stiffness. Seventy-one patients randomly received two cervical restorations placed following two out of three adhesive procedures: (1) the three-step etch-and-rinse adhesive Permaquick applied with the stiff micro-hybrid composite Amelogen Hybrid (PMQ-H, Ultradent), (2) Permaquick applied with the more flexible micro-filled Amelogen Microfill (PMQ-M, Ultradent), or (3) the "gold-standard" three-step etch-and-rinse adhesive Optibond FL applied with the micro-hybrid composite Prodigy (OFL-P, Kerr). The restorations were evaluated after 6 months, 1, 2, 3, 5, 7, and 13 years of clinical service regarding their retention, marginal integrity and discoloration, caries occurrence, preservation of tooth vitality, and post-operative sensitivity. Retention loss, severe marginal defects, and/or discoloration that needed intervention (repair or replacement) and the occurrence of caries were considered as clinical failures. The recall rate at 13 years was 77%. Bond degradation after 13 years was mainly characterized by a further increase in the presence of small but clinically acceptable marginal defects and superficial marginal discoloration. Twelve percent of the OFL-P restorations were clinically unacceptable. In the PMQ group, 22% of the PMQ-M restorations and 26% of the PMQ-H restorations needed repair or replacement. Regarding the clinical failure rate, Optibond FL scored significantly better than Permaquick (McNemar; $p=0.015$). No statistically significant differences were found between the micro-filled and the hybrid composite for each of the parameters evaluated (McNemar, $p>0.05$). After 13 years of clinical functioning, the clinical effectiveness of the three adhesive/composite combinations remained highly acceptable.

Keywords Randomized clinical trial · Etch and rinse · Composite stiffness · Class V · Adhesive

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Introduction

Several contemporary dental adhesives have been reported to posses a favorable "immediate" bond strength to enamel and dentin [1–5]. However, the clinical longevity of bonded restorations is still too short, mainly due to degradation of the adhesive tooth–composite interface [3, 6, 7]. In laboratory circumstances, the durability of this bond is tested using different kinds of artificial aging methods, like simple water storage, long-term thermo-cycling, mechanical loading, and exposure to enzymes and various chemical substances [3, 6, 7]. Such in vitro durability tests have disclosed some further insight in the mechanisms of degradation. Although in general laboratory studies are claimed not to be able to predict the durability of the bond in clinical circumstances, correlation of two recently conducted systematic reviews have suggested some associ-

ation between "aged" laboratory bond-strength data and clinical 5-year class-V retention data [7]. In the literature, the number of medium- to long-term clinical trials is, however, limited. There certainly remains a need for these longer-term clinical trials as the ultimate way to collect scientific evidence on the clinical effectiveness of a restorative treatment.

According to a systematic review of class-V clinical trials, which were published in the period 1998–2009, the three-step etch-and-rinse adhesives exhibited a reasonably good clinical effectiveness, as expressed by a low annual failure rate of 3.9±3.7% [7]. This annual failure rate was higher in the group of all two-step self-etch adhesives (4.7± 7.3%), but lower for the "mild" and "intermediately strong" two-step self-etch adhesives (1.9±3.3%) and the glass ionomers (2±2%) [7]. In a meta-analysis of Heintze et al. [8], evaluating the clinical performance of cervical restorations, the two-step self-etch adhesives performed better than the three-step etch-and-rinse adhesives, followed by the glass ionomers, the two-step etch-and-rinse adhesives, and the one-step self-etch adhesives.

Major shortcomings of three-step etch-and-rinse adhesives are, clinically, their time-consuming application procedure [5] and, from a mechanistic point of view, their relatively weak monomer–collagen interaction. The relatively thick resin–collagen complex or hybrid layer is indeed vulnerable to degradation upon water sorption [6], possibly enhanced to a certain extent by the documented enzymatic degradation process [9–11]. In addition, as all hydroxyapatite in etch-and-rinsed dentin is removed, potential chemical interaction between monomer and hydroxyapatite is expected to be weak in strength of secondary hydrogen bonding or van der Waals forces [12]. On the contrary, primary chemical interaction between the functional monomer and hydroxyapatite was demonstrated for the "mild" self-etch adhesives to contribute to bond durability, thereby imitating the two-fold micro-mechanical and chemical mechanism of bonding typically known for the self-adhering glass ionomers [7, 13, 14]. Nevertheless, traditional three-step etch-and-rinse adhesives are still today regarded as the "gold standard".

Optibond FL (Kerr) and Permaquick (Ultradent) are both particle-filled, ethanol-based three-step etch-and-rinse adhesives and are available on the dental market for more than 10 years. In 1996, we initiated a randomized controlled class-V clinical trial to evaluate the clinical performance of both adhesive systems [15, 16]. After 7 years of clinical functioning [16], we observed a reliable and favorable bonding effectiveness for both adhesives. In continuation of that 7-year report, the study was further followed up, of which now the 13-year recall data are reported. Until now, only four truly (>10 years) long-term clinical trials, evaluating the clinical effectiveness of adhesives for the restoration of non-carious class-V lesions [17–20], have been published in literature.

Two initial hypotheses tested in this clinical trial were as follows: (1) there is no difference in clinical performance between both adhesives, and (2) composite stiffness has no influence on the clinical performance of one of the adhesives.

Materials and methods

In this clinical trial, 71 patients were enrolled. Patients with compromised medical history, severe or chronic periodontitis, extreme caries sensitivity, and heavy bruxism were excluded. One hundred and forty-two non-carious cervical lesions were restored following three experimental procedures with (1) the three-step etch-and-rinse adhesive Permaquick (Ultradent, Salt Lake City, UT, USA; PMQ) combined with the micro-hybrid composite Amelogen Hybrid (Ultradent, PMQ-H), with (2) Permaquick (Ultradent) along with the micro-filled composite Amelogen Microfill (Ultradent, PMQ-M), or with (3) the three-step etch-and-rinse adhesive Optibond FL (Kerr, Orange, CA, USA; OFL-P) in combination with the micro-hybrid composite Prodigy (Kerr, OFL-P). Each patient received two restorations placed in pairs of teeth (first and second premolar at the same side, left and corresponding right incisor, canine, premolar, respectively). A pre-set random table was used to assign two out of the three experimental procedures to the teeth selected, with the tooth with the highest tooth number treated following the first protocol listed, while the tooth with the lowest tooth number was treated using the second protocol.

The age and gender distribution of the patients is listed in Table 1. The distribution of the shape, depth, and degree of sclerosis is presented in Table 2.

The cervical restorations were placed by two experienced dentists. All restorative procedures were carried out under rubberdam isolation. A short 1–2-mm enamel bevel was prepared to increase the surface area for bonding and enhance aesthetics. The adhesive systems were applied according to the manufacturers' instructions. The respective restorative composite was applied incrementally in two or three small layers. Each layer was cured for 40 s with an Optilux light curing unit (Demetron-Kerr). Finishing and polishing was accomplished using pinetree-shaped contouring diamonds (Komet, Lemgo, Germany), rubber points (Eve, Ernst, Vetter, Pforzhein, Germany), flexible discs, and finishing strips (Soflex Pop-on set; 3M, St. Paul, MN, USA).

After 13 years of clinical service, the overall clinical success rate was recorded in terms of (1) restoration retention, (2) enamel and dentin marginal integrity, (3) marginal discoloration, (4) caries occurrence, (5) post-operative sensitivity, and (6) preservation of tooth

Table 1 Distribution of patients recruited and class-V lesions treated according to gender, age, and smoking habits of the patient

Characteristics of patients		Number of patients	Number of lesions
Gender distribution	Male	27	54
	Female	44	87
Age distribution	<18 years	1	2
	20–29 years	1	2
	30–39 years	2	4
	40–49 years	27	53
	50–59 years	21	42
	60–69 years	14	28
	>70 years	5	10
Smoking habits	Non-smoking	65	128
	Smoking	6	12

vitality. These parameters were scored by two experienced and calibrated examiners (different from the operator and fully blinded to the adhesive/composite combination used) using a pre-determined set of criteria introduced by Vanherle et al. [21]. The first four parameters (retention, marginal integrity, marginal discoloration, and caries occurrence) were considered as the principal parameters determining the "overall clinical success rate". Retention loss, severe marginal defects and/or discoloration that needed intervention (repair or replacement), and occurrence of caries along the restoration margins were considered as clinical failures.

Marginal integrity was evaluated using a sharp probe and a mirror. Post-operative sensitivity was measured by blowing a stream of compressed air for 3 s at a distance of 2–3 cm from the cervical restoration, while shielding the adjacent teeth with fingers, and by moving the probe over the restored tooth surface. Tooth vitality was tested by holding a cold carbon dioxide ice stick to the tooth. Clinical photographs were taken at this recall. Any discrepancy in evaluation between the two evaluators was immediately resolved at chair side.

Statistical analysis compared on a pair-wise basis the ratings of retention, marginal integrity, marginal discoloration, and overall clinical success between the experimental and control group using the McNemar test at a significance level of 5% ($p<0.05$).

Correlation between restoration failure and the clinical co-variables, shape and size of lesion, degree of sclerosis, presence of antagonist, and presence of wear facets, was examined using χ^2 test at a significance level of 5% ($p<0.05$).

Results

The 13-year clinical data for the various parameters evaluated are summarized in Table 3.

Table 2 Distribution of non-carious class-V lesions according to shape, depth, and cervico-incisal size of the lesion, degree of sclerotic dentin, presence of an antagonist, presence of incisal wear facets, presence of pre-operative sensitivity, and type of tooth

Characteristics of class-V lesions		Number of lesions
Shape and depth	Wedge-sharp, <1 mm depth	36
	Wedge-sharp, >1 mm depth	56
	Saucer-rounded, <1 mm depth	43
	Saucer-rounded, >1 mm depth	7
Cervico-incisal height	<1.5 mm	13
	1.5–2.5 mm	59
	>2.5 mm	70
Degree of sclerotic dentin	No sclerosis	20
	Slight sclerotic dentin (opaque)	49
	Moderate sclerotic dentin (yellow)	56
	Severe sclerotic dentin (transparent)	17
Presence of antagonist	Antagonist present	126
	Antagonist not present	16
Attrition facet	No attrition facet	18
	Attrition facet on treated tooth	124
Pre-operative sensitivity (to air and/or tactile contact)	Yes	84
	No	58
Tooth distribution	Lower incisor	13
	Lower canine	6
	Lower premolar	74
	Lower first molar	1
	Upper incisor	15
	Upper canine	14
	Upper premolar	19
	Upper first molar	0

Recall rate

The 13-year patient recall rate was 77%. In total, 16 patients were not attending the recall because of the following reasons: five patients died, two patients had severe illness, five patients could not be reached by telephone nor letter, and in four patients the restorations were replaced in function of a total oral rehabilitation plan. In three patients, one of the two restorations was replaced because of extraction (1), placement of a crown (1), replacement by a composite restoration (1), in the latter case because of severe gingival retraction causing dentin hypersensitivity.

Retention rate

The number of lost restorations remained the same as at the 7-year recall for OFL-P (two restorations lost—retention rate=94%) and PMQ-M (five restorations lost—retention rate=90%). One additional PMQ-H restoration has been lost since the 7-year recall, leading to a

Table 3 Evaluation results in percentage at each evaluation period

Recall	Experimental group	Recall rate	Retention rate	Absence of marginal defects	Enamel marginal defects	Small enamel marginal defects	Severe enamel marginal defects	Dentin marginal defects	Small dentin marginal defects	Severe dentin marginal defects	Absence of marginal discoloration	Superficial localized marginal discoloration	Deep generalized restoration discoloration	Absence of sensitivity	Absence of caries recurrence	Preservation of tooth vitality	Overall clinical success rate
6 months	PMQ-H	100	100	51	28	26	2	32	32	0	98	2	0	87	100	100	98
	PMQ-M	100	100	50	27	27	0	38	38	0	96	4	0	92	100	100	100
	OFL-P	100	100	49	21	21	0	40	40	0	98	2	0	91	100	100	100
1 year	PMQ-H	100	100	53	26	24	2	32	32	0	96	4	0	87	100	100	98
	PMQ-M	100	100	45	36	36	0	32	32	0	94	6	0	92	100	100	98
	OFL-P	100	100	47	19	19	0	38	38	0	94	6	0	89	100	100	100
2 years	PMQ-H	100	98	53	28	26	2	28	28	0	91	9	0	87	100	100	96
	PMQ-M	100	98	53	28	28	0	28	28	0	81	17	2	96	100	100	94
	OFL-P	100	100	55	23	23	0	28	28	0	91	9	0	89	100	100	100
3 years	PMQ-H	96	98	51	16	14	2	33	33	0	84	16	0	89	100	100	96
	PMQ-M	100	98	51	24	24	0	34	34	0	74	22	4	96	100	100	92
	OFL-P	96	100	69	18	18	0	16	16	0	89	9	2	100	100	100	98
5 years	PMQ-H	80	89	29	26	23	3	56	56	0	82	18	0	94	100	100	87
	PMQ-M	89	98	43	24	24	0	39	39	0	71	22	7	98	100	100	84
	OFL-P	87	100	55	18	18	0	35	35	0	90	5	5	100	100	100	95
7 years	PMQ-H	75	87	29	45	42	3	48	48	0	76	21	3	97	100	100	81
	PMQ-M	81	92	20	51	46	5	60	57	3	44	50	6	94	100	100	78
	OFL-P	85	94	26	42	42	0	48	48	0	76	18	6	100	100	100	89
13 years	PMQ-H	72	85	9	56	50	6	62	62	0	50	43	7	96	100	100	74
	PMQ-M	85	90	12	66	58	8	58	55	3	29	66	6	100	100	100	78
	OFL-P	70	94	12	61	58	3	70	70	0	45	48	6	97	100	100	88

PMQ-H Permaquick–Amelogen Hybrid, *PMQ-M* Permaquick–Amelogen Microfill, *OFL-P* Optibond FL-Prodigy. All parameters, except for the recall rate, retention rate, and overall clinical success rate, refer only to the retained restorations

retention rate of 85% (four restorations lost). The difference in retention rate between the three groups was not statistically significant (OFL-P vs. PMQ-M—p=0.5; OFL-P vs. PMQ-H—p=0.5; PMQ-H vs. PMS-M—p>0.999; OFL vs. PMQ—p=0.125).

Marginal integrity

Marginal adaptation deteriorated further after 13 years of clinical functioning. Only 10% of the restorations exhibited a perfect marginal adaptation (OFL-P=12%; PMQ-H=9%; PMQ-M=12%). This overall increased marginal deterioration must be attributed to an increase in the percentage of small but clinically acceptable marginal defects at the enamel margin (OFL-P=58%; PMQ-M=58%; PMQ-H=50%) and dentin margin (OFL-P=70%; PMQ-M=55%; PMQ-H=62%), and to a slight increase in the percentage of clinically unacceptable severe marginal defects at the enamel margin (OFL-P=3%; PMQ-M=8%; PMQ-H=6%). At the dentin margin, only one PMQ-H restoration showed a clinically unacceptable severe marginal defect. Regarding marginal integrity, no statistically significant differences were noticed between the three groups (enamel marginal defects—OFL-P vs. PMQ-M, p>0.999; OFL-P vs. PMQ-H, p=0.453; PMQ-H vs. PMQ-M, p>0.999; OFL vs. PMQ, p=0.548; dentin marginal defects—OFL-P vs. PMQ-M, p>0.999; OFL-P vs. PMQ-H, p=0.375; PMQ-H vs. PMQ-M, p=0.343; OFL vs. PMQ, p=0.453).

Marginal discoloration

The percentage of restorations without marginal discoloration decreased further after 13 years (OFL-P=50%; PMQ-M=29%; PMQ-H=45%). For all three groups, marginal discoloration was mostly rated as clinically acceptable superficial discoloration (OFL-P=48%; PMQ-M=66%; PMQ-H=43%) at the enamel margin (OFL-P=32%, PMQ-M=43%; PMQ-H=29%) and/or at the dentin margin (OFL-P=29%; PMQ-M=43%; PMQ-H=29%). Marginal discoloration was most frequently observed at micro-filled PMQ-M restorations, although the difference between the three groups was not statistically significant (OFL-P vs. PMQ-M, p=0.25; OFL-P vs. PMQ-H, p=0.375; PMQ-H vs. PMQ-M, p>0.999; OFL vs. PMQ, p>0.999). Clinically unacceptable deep generalized marginal discoloration was noticed in two OFL-P restorations (6%), in two PMQ-H restorations (6%), and in four PMQ-M restorations (7%). These restorations needed to be replaced.

Post-operative sensitivity

Only two restored teeth (one with OFL-P and one with PMQ-H) were sensitive to air or to tactile contact at the 13-year recall.

Caries occurrence and preservation of tooth vitality

After 13 years of clinical functioning, none of the restored teeth became non-vital due to the placement of the restoration, and none of the restored teeth showed caries recurrence.

Clinical success rate

Considering the key parameters determining the clinical success rate of the restorations after 13 years, only a slight increase in the number of clinical failures was noticed in the PMQ-H group (16%; five lost restorations, two restorations exhibiting a severe marginal defect, two restorations with severe marginal discoloration). In the other two groups, the clinical success rate remained the same as at the 7-year recall; OFL-P: 88% with two lost restorations and one restoration exhibiting a severe marginal defect and severe marginal discoloration, and one restoration exhibiting severe marginal discoloration; PMQ-M: 78% with four lost restorations, three restorations with a severe marginal defect, three restorations with severe marginal discoloration, and one restoration with a severe marginal defect and severe marginal discoloration. No significant difference was noticed between the three experimental groups regarding the overall clinical success rate. However, the OFL group showed a significantly lower clinical failure rate than the PMQ group: 88% and 76%, respectively (OFL-P vs. PMQ-M, p=0.125; OFL-P vs. PMQ-H, p=0.25; PMQ-H vs. PMQ-M, p>0.999; OFL vs. PMQ, p=0.015).

Regarding the influence of the co-variables on restoration failure, significantly more clinical failures were observed in restored teeth showing wear facets (χ^2, p=0.03). No significant correlation was found for the other co-variables (shape and size of lesion, degree of sclerosis, presence of antagonist) (χ^2, p>0.05).

Discussion

Long-term clinical trials are the ultimate test to evaluate the longevity of adhesive restorations; however, they are scarce in literature. Therefore, when adhesive restorations in a clinical trial function well and have a high retention rate at short term, the investigators should be encouraged to continue to follow up the study over a longer time period. The most time-consuming step of the clinical trial is the start of the study; in particular, the selection of the patients, the placement of the restorations, and the baseline evaluation demand a lot of time and effort. The next recall sessions are less time consuming as compared to the baseline evaluation but give highly valuable information regarding the clinical longevity of the restorations. Nevertheless, there are some difficulties with long-term

clinical trials. First, several current long-term clinical trials do not have an optimal study design (no control group available, no randomization, double blind evaluation, etc.) as they were started at a moment that no guidelines were recommended for the setup of a randomized controlled clinical trial [22]. Another difficulty in long-term clinical trials is to obtain an adequately high recall rate in order to achieve sufficient clinical validation. In many long-term clinical trials, a recall rate lower than 50% is reported [18–20, 23, 24].

The present study is randomized, provides a detailed description of the study methodology, exhibited a double-blind evaluation, and showed a rather high recall rate of 77% after 13 years.

Regarding the actual results of this clinical trial, the retention rate was high for both adhesives after 13 years of clinical functioning (OFL-P=94%; PMQ-M=90%; PMQ-H =85%). The retention rate remained quite stable since the 7-year recall as only one extra restoration was lost in the PMQ-H group. No significant difference in retention rate was recorded between the three experimental groups. Such high retention percentages refute the findings of in vitro studies claiming that there are still no durable restorative materials available for the restoration of cervical non-carious class-V lesions [25, 26].

Similar high retention rates were noticed for Optibond Dual cure (Kerr), the predecessor of Optibond FL, after 12 years by Wilder et al. [20] (retention rate=89%) and after 13 years by Boghosian et al. [17] (retention rate= 97%). In the class-V clinical study of van Dijken [19], the retention loss for Optibond Dual cure was obviously higher after 13 years (40%). It is important to mention that in this study all restorations were placed in dentin lesions without intentional enamel involvement. In this respect, only the clinical bonding performance to dentin was evaluated. When the dentin bonding surface is directly exposed to external influences—like long-term water exposure—bond degradation will occur more rapidly, as was shown in several in vitro bond strength studies [27–29].

The high retention rates recorded in this study confirm the superior bonding effectiveness of Optibond FL in vitro [3–5, 7, 27, 30], also after durability testing [27, 31–33]. Because of this reason, Optibond FL is frequently chosen as control adhesive in in vitro studies and is consequently considered as the gold standard. The superior bonding effectiveness and resultant clinical performance in this study must probably to a great extent be attributed to the optimal enamel interlocking and dentin hybridization, as was demonstrated in several ultra-morphologic interface analyses [3, 5, 34].

No in vitro durability studies and medium- to long-term clinical trials are available in the literature from the other three-step etch-and-rinse adhesive, Permaquick.

In this study, composite stiffness (E-modulus of Amelogen Microfill=6.9 GPa; E-modulus of Amelogen Hybrid= 14.7 GPa; measured following Braem et al. [35]) had no significant influence on the retention rate of the class-V restorations after 13 years of clinical service. Similarly, other short-term class-V clinical trials that compared micro-filled versus a hybrid composite, or a flowable composite versus a conventional composite, showed no differences in retention loss [15, 36–40]. Several possible explanations can be given for these findings. First, most non-carious class-V lesions have a relatively small C-factor, by which the mechanical properties of the composite used are more or less unimportant, and the actual adhesive performance determines the eventual clinical outcome to a great extent. Both particle-filled adhesives used in this study (filler rate of OFL=48 wt%; of PMQ=45 wt%) could also have masked the influence of the composite stiffness on the bonding effectiveness, as a thick adhesive layer may have a stress-breaking effect in relieving thermal and occlusal stresses as well as polymerization shrinkage [41, 42]. Indeed, Ritter et al. [24] found that the filled two-step etch-and-rinse adhesive, Optibond Solo (Kerr), was more resistant to fatigue forces. More durable retention of class-V restorations was achieved after 8 years with Optibond Solo (Kerr) than with the unfilled acetone-based two-step etch-and-rinse adhesive Prime&Bond 2.1 (Dentsply): 69% vs. 59%.

The most obvious sign of bond degradation in this 13-year clinical trial was marginal deterioration. Indeed, a further decrease was noticed in the percentage of restorations showing absence of marginal defects (11%) and/or marginal discoloration (41%) since the 7-year recall (25% and 65%, respectively). A small number of restorations need to be repaired or replaced due to the presence of clinically unacceptable severe marginal defects (OFL-P=3%; PMQ-M =11%; PMQ-H=6%) and/or deep marginal discoloration (OFL-P=6%; PMQ-M=6%; PMQ-H=7%) (Fig. 1). In most restorations, marginal deterioration was characterized by the presence of small but clinically acceptable marginal defects and/or superficial marginal discoloration located at the enamel and/or dentin margin (Fig. 2). These small shortcomings only have a minor effect on the clinical effectiveness of the restorations, as they can be removed by refinishing and repolishing of the restoration margins.

Post-operative sensitivity was rarely noticed at the 13-year recall. The risk of post-operative sensitivity is assumed to be higher for etch-and-rinse adhesives than for self-etch adhesives, as the smear layer is completely removed and the dentin tubules are opened. In general, post-operative sensitivity resolves within a short time period after placement. In the present study, the frequency of post-operative sensitivity was already low at baseline and 6 months (10%), and decreased further with time.

Finally, the clinical success rate after 13 years was high for all three adhesive/composite groups. OFL-P showed the

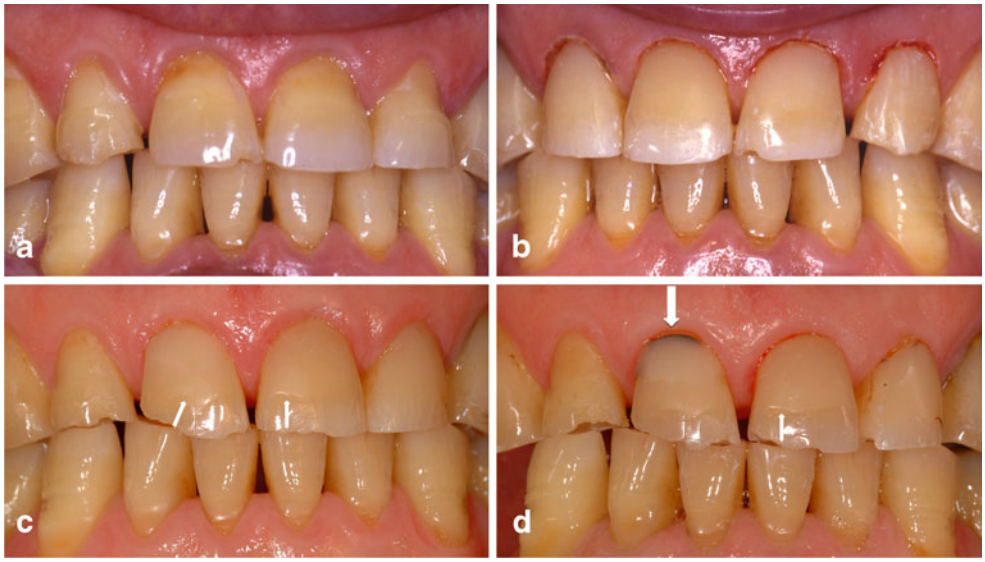

Fig. 1 The cervical lesions on both upper central incisors were restored (21—OFL-P; 11—PMQ-H). **a** Pre-operative view, **b** baseline, **c** 7 years: both restorations showed a small but clinically acceptable marginal defect at the enamel margin (*arrows*). **d** At the 13-year recall, a small marginal defect and severe marginal discoloration were present at the cervical dentin margin of the right central incisor (*11, big arrow*). The restoration was clinically unacceptable and needed to be replaced. The heavy occlusion and articulation (wear facets) on these front teeth could have contributed to this result. The restoration on the 21 showed only a small marginal defect at the enamel side (*small arrow*)

highest percentage, followed by PMQ-M and PMQ-H. Regarding the influence of co-variables on the clinical failure rate, only the "presence of wear facets" present at the restored teeth appeared a statistically significant factor for restoration failure. These wear facets on the teeth are caused by heavy occlusion and articulation. During heavy occlusal loading, stresses become concentrated at the cervical region, causing flexure of the tooth, which may result in the formation of an abfraction lesion [43]. According to Rees and co-authors [44, 45], continuous occlusal loading produces displacements and stresses under the buccal cervical enamel and dentin of restored cervical cavities, increasing crack initiation and encouraging failure of the restoration.

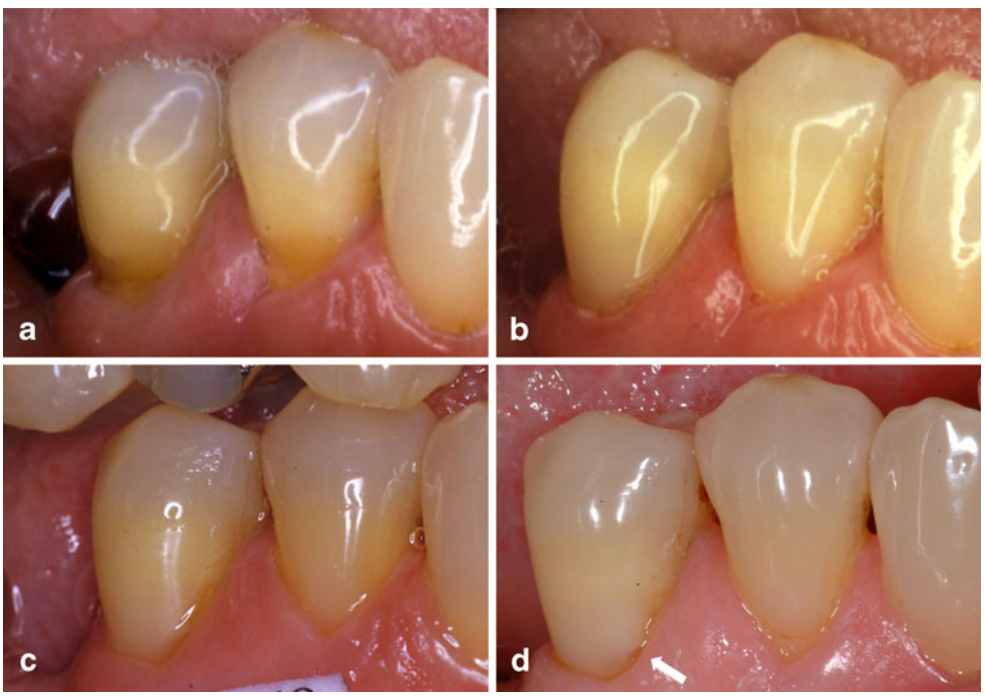

Fig. 2 The cervical lesions on both mandibular premolars were restored (44—PMQ-M; 45—PMQ-H). **a** Situation before treatment, **b** baseline, **c** 3 years, both restorations showed absence of marginal defects and marginal discoloration. **d** Both restorations were still clinically acceptable after 13 years of clinical functioning. Only a small marginal defect was noticed at the cervical dentin margin of the second premolar (*arrow*)

Comparing the two adhesives, Optibond FL showed a significantly higher success rate than Permaquick, by which the first hypothesis was rejected. This still confirms that Optibond FL can be considered as the gold standard among adhesives. Finally, no significant difference was noticed between the three groups, indicating that the stiffness of the composite had no influence on the clinical performance of the class-V composite restorations, by which the second hypothesis in this study was accepted.

Conclusion

At the 13-year recall, the two three-step etch-and-rinse adhesives showed a highly acceptable clinical performance. Although the clinical success rate in the three adhesive/composite groups was high, Optibond FL scored significantly better than Permaquick. The composite stiffness did not affect the clinical longevity of the cervical composite restorations. After this long-term clinical service, marginal defects and discolorations were observed at a steadily growing incidence, but most are of only minor extent that do not require urgent restoration repair and certainly no restoration replacement.

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

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