Meta-Analysis of the Influence of Bonding Parameters on the Clinical Outcome of Tooth-colored Cervical Restorations

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Purpose: To meta-analyze the literature on the clinical performance of Class V restorations to assess the factors that influence retention, marginal integrity, and marginal discoloration of cervical lesions restored with composite resins, glass-ionomer-cement–based materials [glass-ionomer cement (GIC) and resin-modified glass ionomers (RMGICs)], and polyacid-modified resin composites (PMRC).

Materials and Methods: The English literature was searched (MEDLINE and SCOPUS) for prospective clinical trials on cervical restorations with an observation period of at least 18 months. The studies had to report about retention, marginal discoloration, marginal integrity, and marginal caries and include a description of the operative technique (beveling of enamel, roughening of dentin, type of isolation). Eighty-one studies involving 185 experiments for 47 adhesives matched the inclusion criteria. The statistical analysis was carried out by using the following linear mixed model: $\log(-\log(Y/100)) = \beta + \alpha \log(T) + \text{error}$ with $\beta = \log(\lambda)$, where β is a summary measure of the non-linear deterioration occurring in each experiment, including a random study effect.

Results: On average, 12.3% of the cervical restorations were lost, 27.9% exhibited marginal discoloration, and 34.6% exhibited deterioration of marginal integrity after 5 years. The calculation of the clinical index was 17.4% of failures after 5 years and 32.3% after 8 years. A higher variability was found for retention loss and marginal discoloration. Hardly any secondary caries lesions were detected, even in the experiments with a follow-up time longer than 8 years. Restorations placed using rubber-dam in teeth whose dentin was roughened showed a statistically significantly higher retention rate than those placed in teeth with unprepared dentin or without rubber-dam ($p < 0.05$). However, enamel beveling had no influence on any of the examined variables. Significant differences were found between pairs of adhesive systems and also between pairs of classes of adhesive systems. One-step self-etching had a significantly worse clinically index than two-step self-etching and three-step etch-and-rinse ($p = 0.026$ and $p = 0.002$, respectively).

Conclusion: The clinical performance is significantly influenced by the type of adhesive system and/or the adhesive class to which the system belongs. Whether the dentin/enamel is roughened or not and whether rubber-dam isolation is used or not also significantly influenced the clinical performance. Composite resin restorations placed with two-step self-etching and three-step etch-and-rinse adhesive systems should be preferred over one-step self-etching adhesive systems, GIC-based materials, and PMRCs.

Keywords: cervical restorations, Class V, adhesives, composite restorations, abfraction lesions, clinical trials.

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Commonly, noncarious cervical lesions (NCCLs, also called Class V defects) are restored with artificial materials, namely, composite resins or GIC-based materials. Clinical studies with NCCLs are also used to examine the efficacy of a given adhesive system[1] or adhesive class to which the system belongs, and to evaluate the efficacy of restorative procedures and modalities for the treatment of NCCLs.

The main reason for the premature failure of Class V composite restorations is retention loss.[5] Marginal caries hardly affects Class V restorations.[6,15] Earlier studies on Class V adhesive systems show that the prevalence of retention loss increases with increasing observation time,[25] but one study published in 2012 showed less retention loss after 13 years of observation[16] than did another study with the same observation period. However, results of other products published in 2007[25] corroborate

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the earlier findings. It is not yet established in routine clinical practice that roughening of the tooth surfaces prior to Class V restorations is essential for the longevity of the restoration. Mechanical preparation removes sclerotic dentin, which impedes the formation of an adequate hybrid layer.[27,28] Although the roughening of tooth surfaces has not been shown to be a significant factor in the annual failure rate in NCCLs with etch-and-rinse adhesives in several studies,[2,23,24] a meta-analysis published in 2010[6] found significant differences when the tooth surfaces were roughened prior to restoration placement. However, this particular meta-analysis included studies with an observation time of 2 to 3 years. It remains to be seen whether longer observation periods confirm this finding.

The influence of absolute vs relative isolation of the treatment field is another topic that is subject to controversy. A systematic review of Class II restorations carried out by Brunthaler et al[3] found no statistical difference between restorations placed with or without rubber-dam. However, a recently published meta-analysis on the efficacy of Class II resin restorations yielded a different result, showing that the use of rubber-dam isolation significantly diminishes the risk of material fractures.[8]

The type or category of adhesive system or the combination with a specific type of restorative material may also play an important role, as shown by Peumans et al[15] and Heintze et al.[6] A systematic review of Class V clinical trials from 1998 to 2004[15] showed lower failure rates (loss of retention) for three-step etch-and-rinse and two-step self-etching adhesive systems. The same research group found similar results when they performed a further review conducted from 2004 to 2009,[7] with the exception of an improvement in performance of one-step self-etching adhesive systems. These results were partially confirmed by a meta-analysis conducted in 2010,[6] which showed that two-step self-etching adhesive systems performed better than three-step etch-and-rinse systems, followed by glass-ionomer cements, resin-modified glass ionomer cements, two-step etch-and-rinse systems and polyacid-modified resin composites (PMRC). The worst clinical performance was observed in the systems belonging to the one-step self-etching group.

Five years have passed since the first study that systematically evaluated clinical factors on the outcome of cervical restorations in vivo was published.[6] In that study, clinical data from 50 studies were included in a systematic review containing 105 in vivo experiments with 40 different adhesives. That study concluded that two-step self-etching and three-step etch-and-rinse systems should be chosen over one-step self-etching systems and GIC-based materials. The same study concluded that dentin (and enamel) surfaces should be roughened before placement of the restoration.

The goal of the present study was to update the results of that meta-analysis on Class V restorations carried out in 2009[6] by including the same studies with a more strict selection and studies published thereafter. The following hypotheses were examined: 1. Roughening of dentin results in higher retention rates. 2. Beveling of enamel results in higher retention rates and less marginal discoloration. 3. The type of isolation does not influence the clinical outcome. 4. The type of adhesive system or restorative material has an influence on the clinical performance of cervical restorations.

MATERIALS AND METHODS

Selection of Clinical Trials on Class V Restorations

The aim of this review was to update the data collected from a previous study[6] in order to evaluate the clinical performance of cervical restorations and to compare the performance of different adhesive systems. Prospective clinical studies on Class V restorations were searched in MEDLINE and SCOPUS (search period 1955 to 2012, search month 07/2012) applying the guidelines of PRISMA (Preferred Reporting Items for Systemic Reviews and Meta-Analyses). A manual search was performed based on the references of all related articles found. The search words were "Class V" or "cervical" or "abfraction lesion" and "clinical". The inclusion criteria were: 1. prospective clinical trial published in ISI journals involving at least one adhesive system in Class V cavities; 2. minimum duration of 18 months; 3. the study had to report about the outcome variables retention, marginal discoloration, marginal integrity, and marginal caries; 4. the study had to include a description of the operative technique (eg, beveling of enamel, roughening of dentin, or type of isolation). The selected studies after 12/2008 were added to the database created for the meta-analysis published in 2010.[6]

If a clinical trial investigated the effect of etching the enamel by comparing the results with those of etch-and-rinse adhesives, only the data of the etching group were included. The restorative materials and adhesive systems (AS) were grouped as follows:

1. One-step self-etching AS
2. Two-step self-etching AS
3. Two-step etch-and-rinse AS
4. Three-step etch-and-rinse AS
5. Polyacid-modified resin composite (PMRC)

6./7. Resin-modified glass-ionomer cements/glass-ionomer cements (GIC-based materials).

In each experiment, the patients were followed up between 1.5 and 13 years (minimum 1.5 years). The clinical performance was measured via the percentage of retention loss R, the percentage of marginal discoloration MD, and the percentage of detectable margins MI (marginal integrity). The percentage of marginal caries MC was also measured, but since most experiments showed 0% marginal caries, this outcome was not considered in the present analysis. As in Heintze et al,[6] a clinical index defined as $CI = (4R + 2MD + MI)/7$ was calculated to summarize the clinical performance. In the following, all these percentages are expressed as equal to 100% at baseline and decreasing afterwards. They were assessed after 0.5, 1, 1.5, 2, 3, 4, 5, 6, 7, 8, and 13 years (depending on the studies). Since measurements after 13 years were available in only 2 experiments of the same study, and

Table 1 Forty-seven adhesive systems, listed by allocated number, belonging to the 7 different classes (in parentheses) used in 185 experiments from 81 studies included in this meta-analysis

Adhesives systems used			
1 (3) ART Bond	16 (6) GC Conditioner	27 (3) Prime & Bond NT	40 (7) Ketac Conditioner
3 (3) Admira Bond	17 (4) Gluma 2000	29 (1) Prompt-L-Pop	41 (4) Scotchbond 2
5 (4) Clearfil Liner Bond	18 (4) Gluma Solid Bond	30 (3) Single Bond	42 (1) Adper Prompt-L-Pop
6 (2) Clearfil Liner Bond 2	19 (1) Hybrid Bond	31 (4) Scotchbond Multipurpose	43 (3) ALL-BOND 3
8 (2) Clearfil SE Bond	20 (1) iBond	32 (4) Syntac Classic	44 (5) NRC
9 (5) Dyract PSA	21 (3) One Coat Bond	33 (5) Syntac Single Component	47 (1) Clearfil Tri-S-Bond
10 (4) EBS	19 (1) Hybrid Bond	34 (4) Tenure	49 (3) Single Bond Plus
11 (3) Excite	22 (3) One Step	35 (4) Tripton	50 (1) G-Bond
12 (5) F2000 SEP	23 (4) OptiBond FL	36 (1) Tyrian SPE	53 (3) One Step Plus
13 (6) FujiBond L	24 (3) OptiBond Solo	37 (1) Xeno 3	54 (5) PSA Prime/Adhesive
14 (2) ALL-BOND SE	25 (4) Permaquick	38 (6) Vitremer Primer	55 (1) Bond force
15 (1) Futurabond NR	26 (3) Prime & Bond 2.1	39 (7) HTF Conditioner	59 (3) Experimental adhesive (Vericom)

Classes of adhesive systems	Number of experiements
(1) Self-etching 1 step (SE1)	41
(2) Self-etching 2 steps (SE2)	19
(3) Etch-and-rinse 2 steps (ER2)	49
(4) Etch-and-rinse 3 steps (ER3)	37
(5) Polyacid modified resin composites (PMRC)	18
(6) Resin-modified glass ionomer cements (RMGIC)	17
(7) Glass ionomer cements (GIC)	4

since there is a gap of 5 years between 8 and 13 years, the subsequent focus was placed on 8 years of follow-up. In some experiments, an occasional increase rather than a decrease of a percentage was noted over time, which may be due to drop-out of some subjects or to a measurement error.

In Heintze et al,[6] the percentage Y over time T for a given experiment was assumed to decrease linearly according to the following model: $Y = 100 - (\beta + \text{error})^2\ T$, which was equivalent to the linear model $\sqrt{(100\text{-}Y) / T} = \beta + \text{error}$, where the parameter β was dependent on the characteristics of the experiment. A linear deterioration was a good approximation in the first analysis from 2009[6] since there were only 3 years of follow-up. As 8 years of follow-up were now considered, this model was no longer suitable, since a linear deterioration over time may imply a percentage below 0, which is by definition not possible. This is why the following model was considered: $(Y/100) = \exp(-\lambda T\alpha \text{ error})$, where the percentage Y also decreases with time, but not linearly, ensuring that the percentage remains above 0. The parameter lambda (λ) must be positive to ensure that the estimated percentages decrease monotonously; with a negative lambda, the percentages would increase with time.

This model is equivalent to the following linear model: $\log(-\log(Y/100)) = \beta + \alpha \log(T) + \text{error}$, with $\beta = \log(\lambda)$ (such that $\lambda = \exp(\beta)$ is positive). In this model, the parameter β is a summary of the deterioration occurring in an experiment. It depends on the fixed characteristics of the experiment, ie, the factor adhesive as well as the factors preparation (no/yes/missing), beveling (no/yes/missing), and rubber-dam (no/yes/missing). To account for the fact that partly the same subjects were used in the different experiments conducted within the same study, a random study effect was included in the model. To take into account the correlations among the different measurements made in the same experiment, a random experiment effect was also included (which is nested in the study effect). The result was a linear mixed effect model as follows: β = reference value + adhesive effect + preparation effect + beveling effect + rubber-dam effect + study random effect + experiment random effect.

Each experiment was weighted according to the number of subjects involved.

The two random effects as well as the error term were assumed to be normally distributed. The reference value refers to the adhesive No 1 of the list of adhesive systems (Table 1, ART Bond) without roughening, without beveling, and without rubber-dam (in an average experiment from an average study). This reference value is thus a summary measure of the deterioration, ie, the clinical performance for this adhesive system. To obtain a summary measure of the clinical performance for the other adhesives, the coefficients corresponding to the different adhesives estimated in the model should be

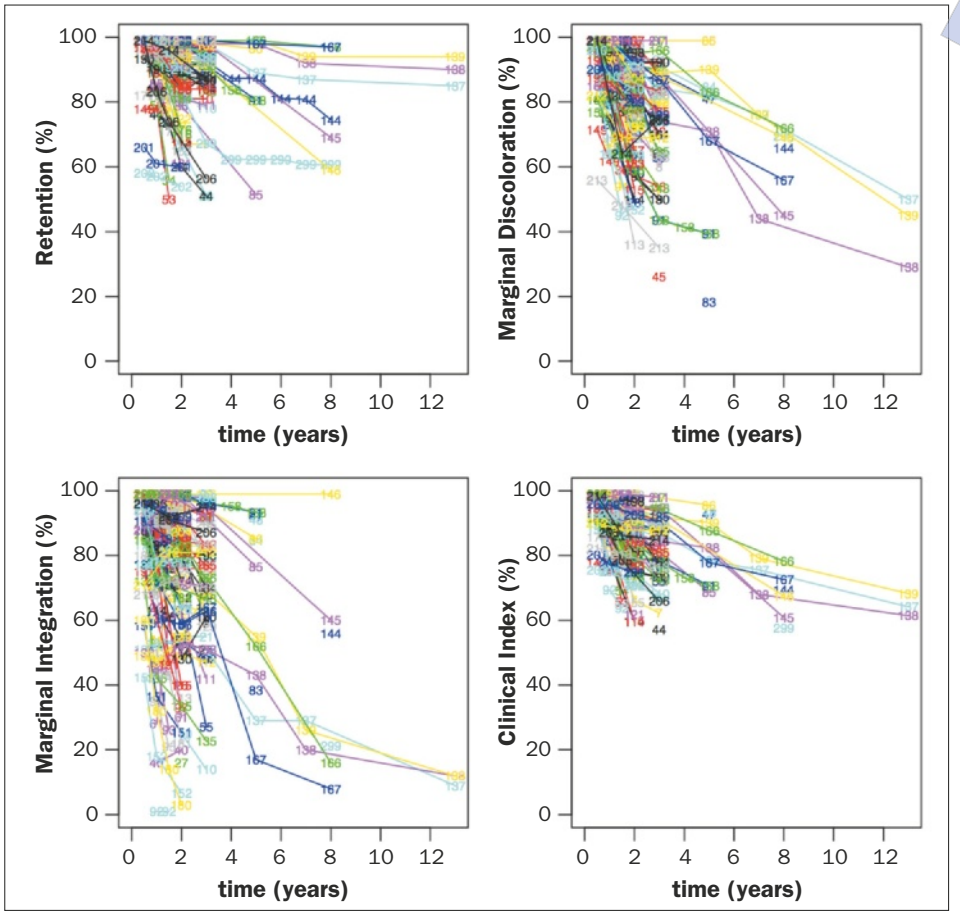

Fig 1 Deterioration of clinical performance (percentage of retention [R], marginal discoloration [MD], marginal integrity [MI], and clinical index [CI] over time) in the different experiments. The numbers indicate the number of each experiment.

added to this reference value (since 47 adhesives were examined, the adhesive effect was represented by 46 coefficients in this model). To fit a linear mixed effect model, the lme routine was used from the package nlme implemented in the free statistical package R. Using this routine, it was possible to weight a percentage Y according to the denominator used for its calculation, ie, the number of patients available at a given point in time. Thus, the percentages calculated from many patients received a higher weight than the percentages calculated from a small sample.

RESULTS

Data on the clinical performance of 47 adhesives were analyzed in patients from 185 experiments conducted in 81 studies (between 20 and 134 patients per experiment and between 1 and 6 experiments per study, each study involving up to 4 different adhesives). Figure 1 shows the deterioration of clinical performance over time in the different experiments included.

Table 1 shows all the adhesive systems used in the studies included in this meta-analysis (see also Appendix 1).

The following distributions for the factors beveling, roughening, and rubber-dam (no/yes/missing) were found in the 185 experiments: beveling: 100/77/8; roughening: 98/75/12; rubber-dam: 98/71/16. No experiment was excluded when fitting our model, where the three factors above were treated as factors with three categories (including a "missing" category).

The mean retention rate of cervical fillings was 90.8%, 87.7%, and 76.2% after 3, 5, and 8 years, respectively. The percentage of restorations without marginal discoloration and without detectable margins was lower, resulting in a value for the clinical index of 84.0%, 82.6%, and 67.7% after 3, 5 and 8 years, respectively.

The factors roughening, beveling, and rubber-dam are presented in Fig 2. Experiments with roughening had significantly less retention loss and a better marginal integrity than experiments without (eg, $p = 0.001$ for the clinical index CI, 0.004 for MI, and 0.005 for R). No significance was found for MD ($p = 0.279$). Experiments with rubber-dam had significantly less retention loss than experiments without rubber-dam (eg, $p = 0.011$ for CI, and 0.002 for R), although no significance was observed for the outcomes MI ($p = 0.852$) and MD ($p = 0.138$). Experiments with beveling did not significantly differ from experiments without beveling for any factor ($p = 0.62$ for CI, 0.08 for MI, 0.43 for MD, and 0.194 for R). Interaction between the factors roughening and rubber-dam was tested (based only on those experiments where both factors were present): no significance was found ($p = 0.096$,

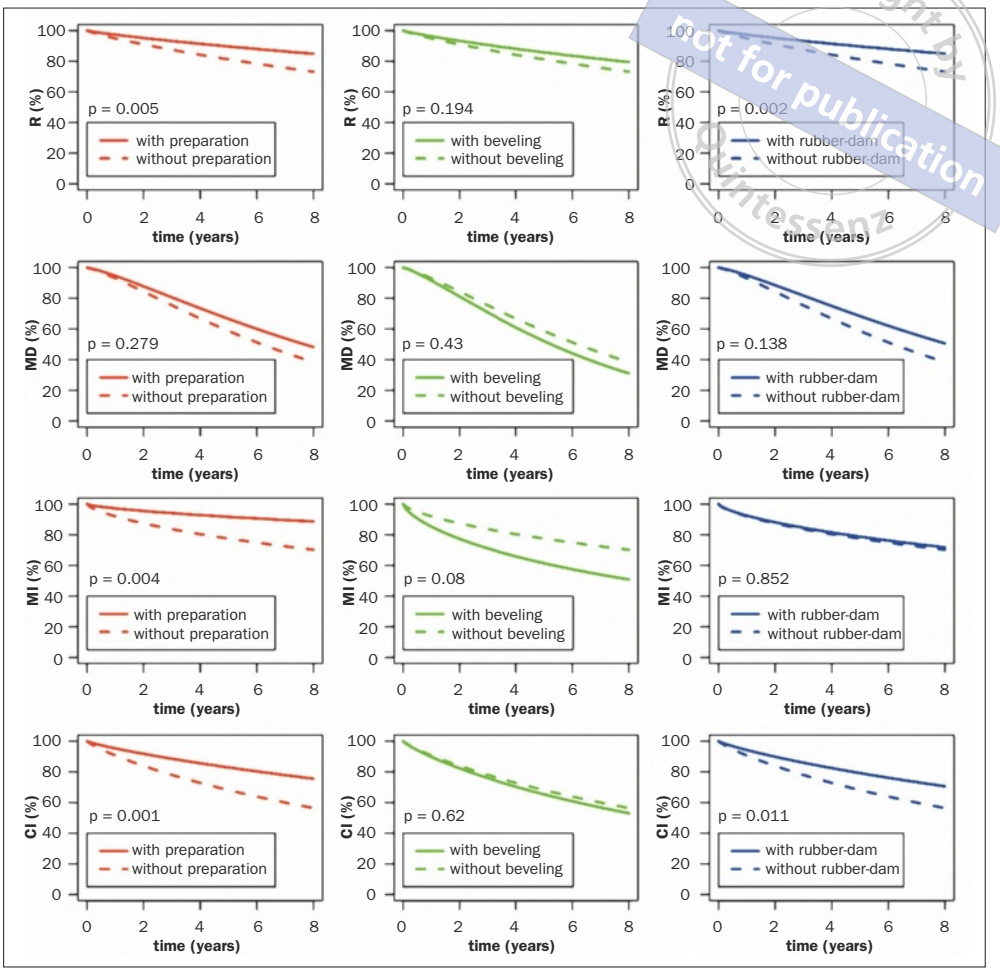

Fig 2 Estimation of the median deterioration over time of the clinical performance (percentage of retention [R], marginal discoloration [MD], marginal integrity [MI], and clinical index [CI]) according to the linear mixed model as a function of the factors preparation or roughening (left panels), beveling (middle panels), and rubber-dam (right panels).

$p = 0.747$, $p = 0.260$, and $p = 0.813$ for R, MD, MI, and CI, respectively).

The deterioration was better estimated for those adhesives evaluated by several studies than for those adhesives evaluated only in a few studies. To avoid an overinterpretation of the results of these plots (Fig 3), only 12 adhesives with measurements from at least 5 studies are shown (adhesives No. 8, 9, 16, 22, 23, 27, 29, 30, 31, 38, 40, 47). For instance, it is evident that adhesive No. 8 (Clearfil SE Bond) was the best and adhesive No. 22 (One-Step) was the worst with respect to the clinical index (CI).

Figure 3 shows the median deterioration estimated for the different adhesives with respect to R, MD, MI and CI, which were tested in at least 5 different clinical trials.

Table 2 shows the distribution regarding the factors rubber-dam, beveling, and roughening.

The adhesive systems/restorative materials were grouped in 7 different classes. Classes 6 and 7 (RMGIC and GIC) were considered as one class for the statistical analysis. The factor "class of adhesive" was globally significant for each outcome, except MI, in a likelihood ratio test ($p < 0.001$, $p = 0.006$, $p = 0.054$, and $p = 0.002$ for R, MD, MI, and CI, respectively). When comparing two by two the classes of adhesive in a post-hoc test applying a Bonferroni correction, one-step self-etching adhesives had a significantly worse clinical index than did two-step self-etching and three-step etch-and-rinse adhesives ($p = 0.026$ and $p = 0.002$), whereas GIC-based materials had a significantly better retention rate than did one-step self-etching, two-step etch-and-rinse, and PMRC ($p = 0.005$, $p < 0.001$, and $p < 0.001$), see also Fig 4.

Interaction between the factors "class of adhesive" and "beveling" was also tested (based only on the experiments where the factor "beveling" was present), and was significant for most outcomes: $p < 0.001$, $p = 0.001$, $p = 0.497$, and $p = 0.001$ for R, MD, MI, and CI, respectively. In fact, this was because the factor "beveling" was significantly associated with an acceleration of the deterioration for GIC-based materials (Class 6/7). No significant interaction was found between the factors "class of adhesive" and "rubber-dam" (based only on the experiments where the factor rubber-dam was present): $p = 0.933$, $p = 0.053$, $p = 0.434$, and $p = 0.620$ for R, MD, MI, and CI, respectively.

Figure 5 shows the Spearman correlations "rho" among the four measures of clinical performance (R, MD, MI, CI) obtained via the coefficients estimated in the linear mixed model (here parameterized so that a higher value means better clinical performance) calculated over the 47 adhesives. Interestingly, although the clinical index places more weight on R and MD than on MI, the correlation

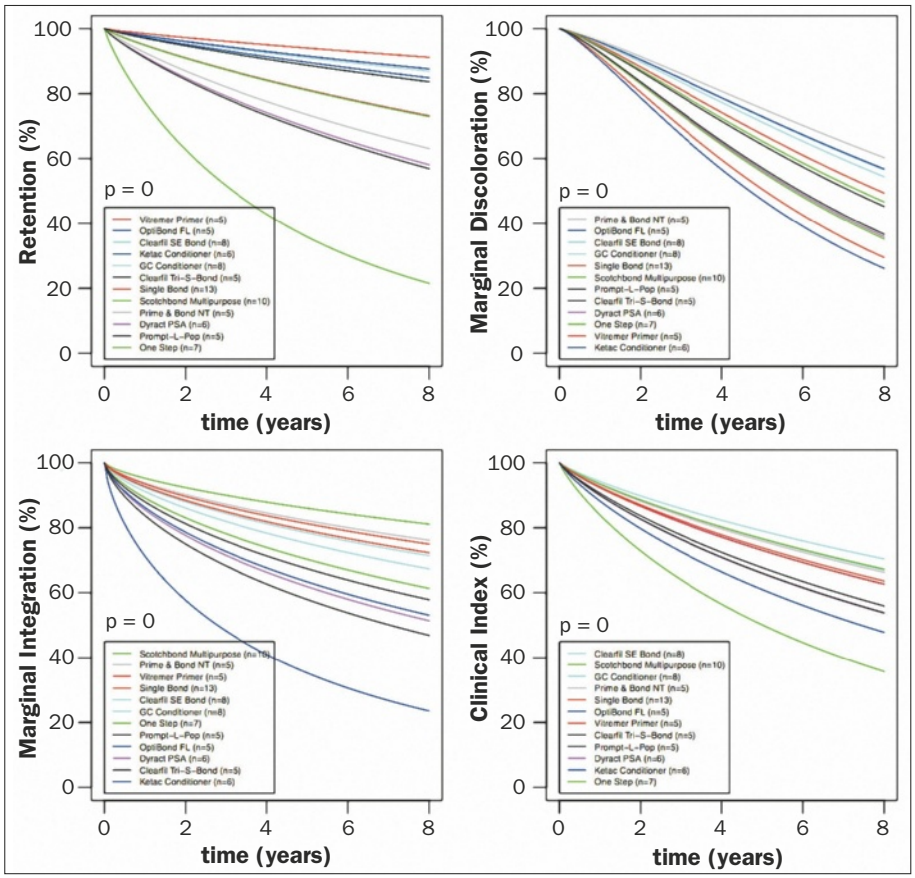

Fig 3 Estimation of the median deterioration over time of the clinical performance (percentage of retention [R], marginal discoloration [MD], marginal integrity [MI], and clinical index [CI]) according to the linear mixed model for the 12 adhesives with measurements from at least 5 studies (where n refers to the number of studies available for each adhesive).

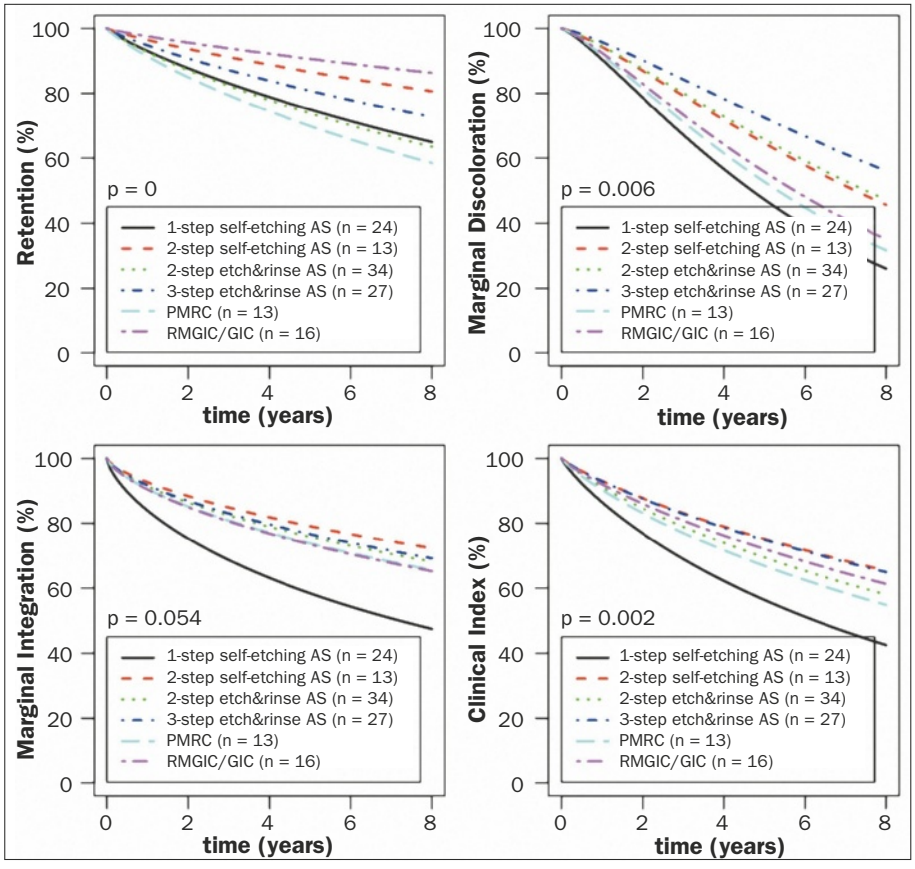

Fig 4 Estimation of the median deterioration over time of the clinical performance (percentage of retention [R], marginal discoloration [MD], marginal integrity [MI], and clinical index [CI]) according to the linear mixed model as a function of the class of adhesive (where n refers to the number of studies available for each class of adhesive).

Table 2 Distribution regarding the factors rubber-dam, beveling, and roughening

	Rubber-dam			Beveling			Roughening		
	Yes	No	Missing	Yes	No	Missing	Yes	No	Missing
Number of experiments	71	98	16	77	100	8	75	98	12

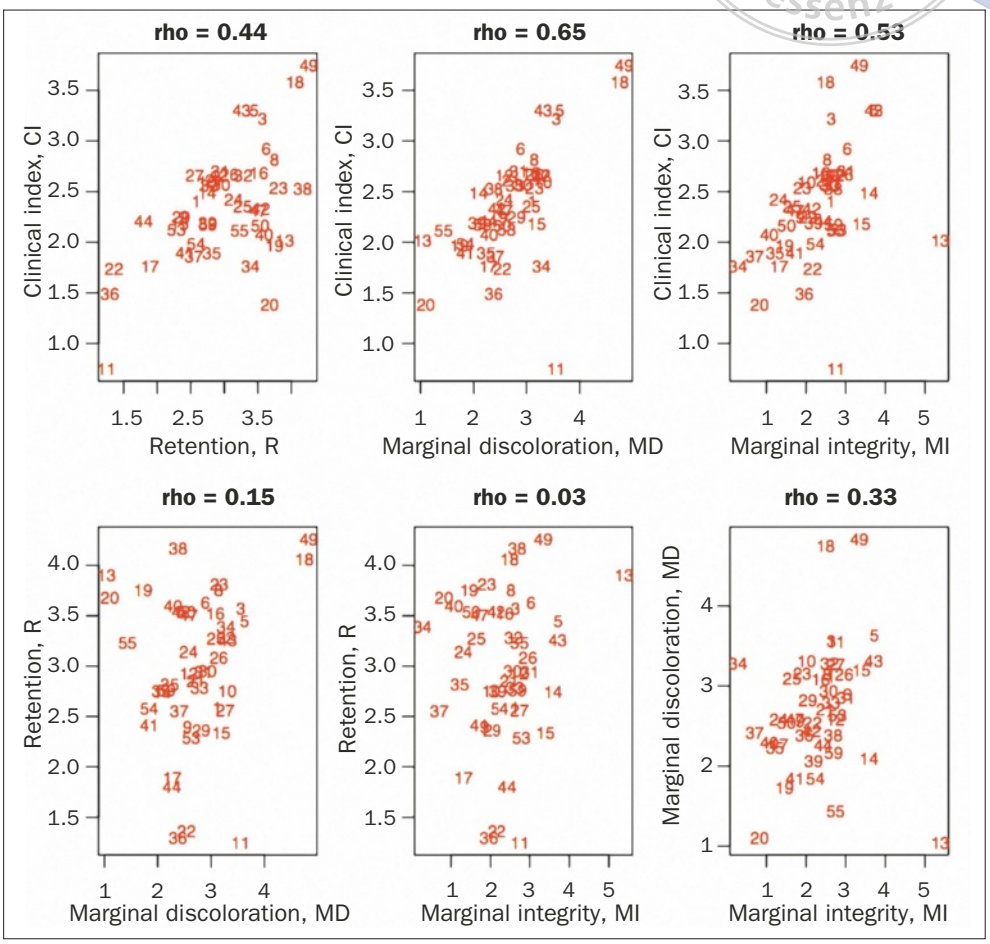

Fig 5 Spearman correlations among the four measures of clinical performance (R, MD, MI, CI) obtained via coefficients estimated in a linear mixed model (the higher the value, the better the clinical performance) calculated for the 47 adhesive systems. The numbers refer to the adhesive system (see Table 1).

was higher between CI and MI than between CI and R or between CI and MD. This is due to the fact that R showed a lower variability among the adhesive systems than did MD and MI. Correlations between R and MD and between R and MI were not significant, whereas the correlation between MD and MI was (rho = 0.33, p = 0.024).

DISCUSSION

The present meta-analysis systematically evaluated the influence of bonding parameters on the clinical outcome of cervical restorations in vivo. Clinical evaluation of this type of restorations is important due to their use as evaluators for clinical performance of dental adhesives and because of an emerging public health issue: the prevalence of NCCLs is increasing in the population, especially in industrialized countries. where more patients retain their own teeth well into old age. It is known that the etiology of NCCLs depends on multiple factors,[12] and the patient's risk factors vary considerably. Therefore, several factors can directly influence the retention and general clinical performance of Class V restorations, for example, occlusion, dentin sclerosis, and patient age.[4,17,23]

In the present study, data on the clinical performance of 47 adhesives was measured on subjects from 185 experiments conducted in 81 studies, which means that compared to the first meta-analysis,[6] 35 studies with 80 experiments were added. Eight new adhesives which fulfilled the inclusion criteria were tested in this period. The same clinical index used in the first publication[6] was used in this study (CI= (4 x R+ 2 x MD + 1 x MI)/7). The rationale for creating a clinical index is that a better statistical analysis can be conducted. The weighing of the three outcome variables (4x for R, 2x for MD, 1x for MI, and all divided by 7) was based on the following considerations: retention loss is the most obvious sign of failure of a

cervical restoration and is the most reliable diagnostic evaluation criterion with little variability between different evaluators, and marginal discoloration and marginal integrity are outcome variables which may show a greater variability between different evaluators; although they are not generally regarded as primary failure, they deserve attention. It is true that retention is objective and the other parameters rather subjective, but the results are also reported separately for each parameter. Since the main reason for the treatment of NCCLs is the unpleasant esthetic appearance of cervical defects (followed by hypersensitivity), discoloration of restoration margins and marginal integrity should also be included, as many practitioners confound marginal discoloration with marginal caries and replace the restorations unnecessarily. Furthermore, marginal discoloration may impair the esthetic appearance, which again might be a reason for replacement. No other clinical parameters, such as color match or post-operative hypersensitivity, were included in the present analysis, because most of the studies did not report them. With regard to marginal caries, the prevalence was close to 0, even after 8 years; therefore, this parameter was excluded from the statistical analysis.

Although great care was taken to reduce bias and perform a precise collection of the data, the present meta-analysis had some limitations, as described below.

During the last 30 years, there have been many "generations" and types of adhesive product designs. In the collection of data, major efforts were made to correctly classify each adhesive system, most often by Internet search.

The different assessment criteria (eg, USPHS, A-B-C; USPHS, A-B-C-D; FDI 1-5.) were normalized as far as possible by combining scores, eg, FDI 1 and 2 were combined with USPHS A, FDI 3 was allocated to USPSH B, and FDI 4 and 5 were combined with USPHS C.

Over the past decades, several techniques have been used with more or less enthusiasm by clinicians and tested in clinical trials. They have certainly had an impact on the bonding performance. The best example concerns dentin moisture vs dryness, with methods that require drying of dentin, leaving dentin wet, leaving dentin moist, or slightly drying and then rewetting dentin. Since many studies do not report about the exact operative procedure, it was not possible to take these parameters into account.

To facilitate the inclusion of clinical trials, it would be desirable if they examined restorations of similar size, geometry, and extent; if not, at least differences should be reported as well as failures related to those differences. However, the size and precise characteristics of each restoration are usually not reported in the studies. Therefore, it is impossible for us to categorize and account for these parameters. In addition, since we included a large number of studies, we may assume that the variability of cavity size and hard tissue characteristics from one study to another study is great enough to justify general conclusions that do not need restrictions with regard to the above-mentioned parameters.

As a rule, the introduction of new adhesive systems onto the market is based on laboratory tests, ie, bond strength tests of various kinds, while clinical evaluations tend to be exceptions.[26,29] Although several adhesive systems showed good bond strength values (uTBS) to dentin,[11] high loss rates were reported only after some years of clinical service.[14,17] Only three publications on the correlation of bond strength tests and the clinical performance of restorations placed with adhesive systems have been published so far. In one of these studies,[7] the microtensile bond strength data of 15 adhesive/restorative systems placed by the same operator were correlated with the clinical studies of noncarious cervical Class V restorations. No correlation was found between the retention rate of cervical restorations after three years and the microtensile test results after 8 h or 6 months of water storage. Some moderate correlation was found between marginal staining and bond strength values after 6 months of water storage, and another study showed some correlation between retention rates of Class V restorations after 5 years with laboratory specimens that were submitted to artificial aging, including mechanical stressing of bonded bars.[30]

Since the success of Class V restorations mainly relies on adhesion to the cavity with almost no mechanical retention, the impregnation of the dentin substrate by the resin monomers and the stability of the bonded interface (homogeneous hybrid layer) are of paramount importance for their clinical performance.[13] Many influential factors have been mentioned in the literature, such as roughening of the surface, beveling of enamel, use of rubber-dam, type of the adhesive, and the technique used to apply it. For example, vigorous agitation of the adhesive (rubbing technique) seems to increase retention rates,[13] since a better impregnation of the dentin substrate improves the durability of the hybrid layer. This factor seems to be especially critical for resin monomers with a high molecular weight, such as those present in simplified etch-and-rinse adhesives. Due to their limited diffusion into the wet demineralized dentin,[14,31] these monomers produce an uneven resin penetration with a high concentration at the surface and a lower concentration in the deepest area of the demineralized zone. In accordance with the results published in 2010,[6] adhesives belonging to adhesive class 1 (one-step self-etching) performed poorest and adhesives belonging to class 2 (two-step self-etching) performed the best. Another factor that has been disregarded in the literature is the performance of flowable composites in NCCLs compared to high-viscosity resin composite. Their use is very rare in NCCL restorations. Only seven studies that used flowable composites fulfilled the inclusion criteria. Not enough data were found to perform a meaningful analysis exclusively for them.

The results of the same adhesive system in different studies vary considerably. To date, it is not clear whether the high variability (also shown in in vitro studies[7]) is due to operator-related factors, patient related-factors, or the technique sensitivity of the product. It has been shown that the operator plays an important role in in vitro studies, since differences between experienced and inexperienced opera-

tors influenced the results in some studies irrespective of the adhesive system.[20,22] When instructions for use were followed, even the more complicated adhesive systems (three-step etch-and-rinse) produced better and more predictable bond strength results with inexperienced operators than did the simplified systems (one-step self-etching),[20] and two-step self-etching adhesive systems produced better results than did two-step etch-and-rinse systems.[22] These results corroborate the data found in the present meta-analysis: three-step etch-and-rinse and two-step self-etching performed better for all clinical parameters than did simplified systems, such as two-step etch-and-rinse and one-step self-etching. Regarding retention, the analysis for different classes of adhesives revealed that both the two-step self-etching adhesive systems and the glass-ionomer cements showed the best retention rate over time, whereas the one-step self-etching adhesives and the compomers had the lowest retention rate (Fig 3).

Variable sample sizes, different operative techniques, and lack of calibration between the evaluators need to be added to the variation in operator experience. Due to the reasons mentioned before, it is necessary to standardize the design of clinical trials, since many clinical variables are simultaneously involved and the Ryge criteria are no longer precise enough.[10] New clinical criteria for the evaluation of restorations were published in 2007 by a board of experienced clinicians; these criteria were also accepted by a FDI committee.[10] Unfortunately, more recent studies could not use these new criteria because they had already started at the time of the publication.[13]

It is well known that the type of dentin and especially the degree of sclerosis can have an effect on the clinical performance. Some studies classified the defects with a dentin sclerosis scale,[9,18,19] but unfortunately most of the studies did not relate the failures to the age of the patients or to the level of sclerosis previously classified, which makes the correlation of these factors impossible.

In order to improve the bonded surface, many investigators roughen the surfaces of NCCLs prior to restoration. The idea is to remove contaminated and hypermineralized dentin surfaces that can have a negative effect on the formation of the hybrid layer. However, early studies showed that this factor was not significant with regard to annual failure rates.[2,23,24] The present meta-analysis confirmed the earlier meta-analysis.[6] Both showed that the effect of dentin/enamel roughening significantly increased the retention rate of Class V restorations. This effect did not necessarily apply to each class of adhesive system, because not enough data was available to perform a meaningful analysis for each adhesive class separately.

The present study confirmed that beveling of the enamel did not improve the clinical performance on a general basis. In restorations placed with GIC-based materials (RMGIC/GIC), beveling was significantly associated with an acceleration of the deterioration of marginal integrity. If enamel is beveled, glass ionomer is placed in thin layers on the beveled enamel, and due to the low mechanical properties of glass ionomer and the low bond strength to enamel, marginal fractures may occur over time, compromising the marginal seal.

Experiments in which rubber-dam was used were related to significantly less retention loss and marginal discoloration than experiments without rubber-dam (eg, $p = 0.011$ for the clinical index CI; no significance was found for the outcome variable MI) (Fig 2). This result was in contrast to the first meta-analysis published in 2010[6] which showed no significant impact of rubber-dam isolation on any of the examined variables. On the other hand, the present results agree with a meta-analysis on direct posterior Class II restorations,[23] which found that the application of rubber-dam (absolute isolation) compared to cotton rolls and suction (relative isolation) significantly enhanced the longevity of the restorations by reducing material fractures. In this situation, moisture during application and polymerization of the composite could have reduced the mechanical properties of the posterior restorations. In the case of the cervical restorations, moisture may promote the infiltration of saliva and/or sulcular fluid along the restoration interface, which creates more microleakage and thus compromises the bond to dentin. However, no evidence in the literature has been found to substantiate this hypothesis. However, a possible confounder is the operator. Dentists who place rubber-dam may be more skilled and/or are more careful and pay more attention to the operative procedures than those dentists who work only with cotton rolls and saliva ejector. Thus, a higher level of operator skill combined with more careful operative procedures can enhance the longevity of composite resin restorations both in posterior and cervical restorations. To elucidate the influence of absolute vs relative isolation on clinical parameters, we need well-designed, prospective, long-term multicenter clinical studies, also with general practitioners, using a split-mouth design in which the restoration on one side of the mouth is placed with absolute isolation and on the other side with relative isolation.

Clinical Recommendations

Within the limitations of the present analysis, the following recommendations can be made.

The clinician should roughen the dentinal (and enamel) surface, as this measure increases the durability of the cervical restoration. The first hypothesis was accepted (eg, $p = 0.001$ for the clinical index CI, 0.004 for MI, and 0.005 for R). The additional beveling of the enamel can be omitted, as this procedure does not influence the clinical performance of the restoration ($p = 0.62$ for CI, 0.08 for MI, 0.43 for MD, and 0.194 for R). Thus, the second hypothesis – positive correlation of enamel beveling with clinical performance – was rejected. For glass-ionomer cement restorations, beveling of enamel should be completely omitted, since it decreases the longevity of this material in Class V restorations.

If the clinical situation allows it, absolute isolation with rubber-dam should be applied, since the use of rubber-dam positively influences the performance of Class V restorations. Experiments which employed rubber-dam had significantly less retention loss than experiments which did not, although no significance was observed for marginal integrity ($p = 0.852$) and marginal discoloration

($p = 0.138$); the third hypothesis was therefore rejected. One-step self-etching adhesives had a significantly worse clinical index than did two-step self-etching and three-step etch-and-rinse adhesives ($p = 0.026$ and $p = 0.002$). This finding allowed the 4th hypothesis to be accepted. Not enough evidence exists for the use of flowable composites in combination with any kind of adhesive system. Although GIC-based materials perform well with regard to retention, their rather poor esthetic properties may make them inadequate for this indication, especially in the anterior and premolar region.

CONCLUSIONS

Due to the increased number of patients reaching higher ages, noncarious cervical lesions and dentin hypersensitivity (DH) are increasing in prevalence. In the absence of DH, cervical defects should only be restored if the esthetic appearance is compromised and if the patient has a strong desire to have the lesion restored. If the application of fluoride or desensitizer fails to reduce sensitivity, cervical defects should be restored. Traditionally, cervical defects are restored with artificial materials, namely, composite resins or glass-ionomer cements and their modifications. Since the success of Class V restorations mainly relies on adhesion to the cavity with almost no mechanical retention, the adhesive system plays the most important role. The clinician should select an adhesive system with proven good clinical performance for this indication.

This analysis revealed that the clinical performance of cervical restorations is significantly influenced by the type of adhesive system and/or the adhesive class the systems belongs to and by the fact if the dentin is roughen or not, as previously proven in a meta-analysis performed 5 years ago.[6] Beveling of the enamel had no significant influence on any clinical parameters and was independent of the adhesive class, with the exception of glass-ionomer cements, which performed worse when the enamel had been beveled. The type of isolation had a significant influence on the long-term result: restorations placed with rubber-dam performed significantly better in the long run than those placed without rubber-dam.

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APPENDIX 1

Adhesive systems and their allocated number evaluated in 81 clinical trials (for details of references, see Appendix 2 and references above)

Allocated number and adhesive system	Clinical trial
1. A.R.T. Bond	18,72
3. Admira Bond	1,23
5. Clearfil Liner Bond	8,46,79
6. Clearfil Liner Bond 2	7,39,75,
8. Clearfil SE Bond	1,3,16,53,54,57,69,74
9. Dyract PSA	4,19,29,33,42
10. EBS	19,73
11. Excite	30
12. F2000 SEP	25,27,32,49
13. Fuji Bond LC	54
14. ALL-BOND SE	41
15. Futurabond NR	6,36
16. GC Conditioner	4,12,15,19,30,33,71
17. Gluma 2000	8,35,79
18. Gluma Solid Bond	64
19. Hybrid Bond	1,66
20. iBond	64
21. One Coat Bond	19,38,75
22. One Step	10,11,13,61,65,73,81
23. OptiBond FL	24,30,56,76,78
24. OptiBond Solo	27,63,68
25. Permaquick	56,74,78
26. Prime & Bond 2.1	2,48,63,68
27. Prime & Bond NT	23,27,45,51,69

Allocated number and adhesive system	Clinical trial
29. Prompt-L-Pop	22,43,58,75
30. Single Bond	9,12,21,22,32,39,43,51,61, 62,65,80,81
31. Scotchbond Multipurpose	8,9,17,37,47,49,50,52,72,79
32. Syntac Classic	8,29
33. Syntac Single Component	2,4,15,27
34. Tenure	77
35. Tripton	77
36. Tyrian	13,44
37. Xeno III	66,67
38. Vitremer Primer	4,30,33,42,49
39. HTF Conditioner	33
40. Ketac Conditioner	5,14,24,20,59,71
41. Scotchbond II	25,59
42. Adper Prompt-L-Pop	37
43. ALL-BOND 3	60
44. NRC	49
47. Clearfil Tri-S Bond	16,20,26,28,38,40
49. Single Bond Plus	52
50. G-Bond	20,38,76
53. One Step Plus	31,46
54. PSA Prime/Adhesive	23,52
55. Bond Force	52
59. Experimental adhesive (Vericom)	37

APPENDIX 2

Literature: Studies used in the previous meta-analysis (b), studies added to this meta-analysis (c)

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