Clinical Effectiveness of Direct Class II Restorations – A Meta-Analysis

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Purpose: More than five hundred million direct dental restorations are placed each year worldwide. In about 55% of the cases, resin composites or compomers are used, and in 45% amalgam. The longevity of posterior resin restorations is well documented. However, data on resin composites that are placed without enamel/dentin conditioning and resin composites placed with self-etching adhesive systems are missing.

Material and Methods: The database SCOPUS was searched for clinical trials on posterior resin composites without restricting the search to the year of publication. The inclusion criteria were: (1) prospective clinical trial with at least 2 years of observation; (2) minimum number of restorations at last recall = 20; (3) report on dropout rate; (4) report of operative technique and materials used; (5) utilization of Ryge or modified Ryge evaluation criteria. For amalgam, only those studies were included that directly compared composite resin restorations with amalgam. For the statistical analysis, a linear mixed model was used with random effects to account for the heterogeneity between the studies. P-values under 0.05 were considered significant.

Results: Of the 373 clinical trials, 59 studies met the inclusion criteria. In 70% of the studies, Class II and Class I restorations had been placed. The overall success rate of composite resin restorations was about 90% after 10 years, which was not different from that of amalgam. Restorations with compomers had a significantly lower longevity. The main reason for replacement were bulk fractures and caries adjacent to restorations. Both of these incidents were infrequent in most studies and accounted only for about 6% of all replaced restorations after 10 years. Restorations with macrofilled composites and compomer suffered significantly more loss of anatomical form than restorations with other types of material. Restorations that were placed without enamel acid etching and a dentin bonding agent showed significantly more marginal staining and detectable margins compared to those restorations placed using the enamel-etch or etch-and-rinse technique; restorations with self-etching systems were between the other groups. Restorations with compomer suffered significantly more chippings (reparable fracture) than restorations with other materials, which did not statistically differ among each other. Restorations that were placed with a rubber-dam showed significantly fewer material fractures that needed replacement, and this also had a significant effect on the overall longevity.

Conclusion: Restorations with hybrid and microfilled composites that were placed with the enamel-etching technique and rubber-dam showed the best overall performance; the longevity of these restorations was similar to amalgam restorations. Compomer restorations, restorations placed with macrofilled composites, and resin restorations with no-etching or self-etching adhesives demonstrated significant shortcomings and shorter longevity.

J Adhes Dent 2012;14:407–431.
doi: 10.3290/j.jad.a28390
Submitted for publication: 01.12.11; accepted for publication: 20.05.12

Worldwide, multisurface restorations in permanent premolars and molars are the most frequent type of dental restorations. This is due to the localization of caries, which primarily occurs on the occlusal and proximal surfaces of posterior teeth.[67] Although minimally invasive operative techniques and instruments are available, the majority of dental practitioners still opt for the traditional Class II preparation design based on the guidelines that were established by G.V. Black in 1910.[9] In industrialized countries, the most frequently used materials to restore posterior lesions are composite resins of various kinds, which are placed according to the adhesive technique involving the conditioning of both dentin and enamel.

The usage of composite resins has surpassed the usage of amalgam over the last 10 years, but amalgam is still widely used in many countries.[68] Based on the market volume and materials sold, it can be calculated

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that more than 500 million direct dental restorations are placed each year in the world. Of these. about 261 million are direct composite resin restorations, followed by 236 million amalgam restorations and about 26 million compomer restorations.[115] These numbers mean that every 10th person on earth receives one restoration per year on average. The composite and compomer restorations also include anterior restorations in both primary and permanent teeth. However, the distribution shows strong regional differences. Almost no amalgam restorations are placed in Scandinavian countries, whereas in central Europe and the US, more teeth are restored with composite than with amalgam, and in southern and eastern European countries as well as in developing countries, it is vice versa. The above-mentioned estimates suggest that the direct placement of a dental restoration represents one of the most prevalent medical interventions in the human body worldwide. Therefore, there should be great interest in the efficacy of this type of medical/dental treatment. Different groups that are involved in this type of intervention should look for valid data, such as the academics who teach dentistry, the dental professionals who place the restorations, insurance companies or other third parties which pay for them in some countries, and last but not least, the patient who receives the restoration and in many countries must also pay for it.

Data from the last 10 to 20 years indicate that – as far as the longevity is concerned – there is no significant difference between posterior composite resin and amalgam restorations in controlled clinical trials at universities.[62] A large randomized clinical trial of 1748 restorations placed in 8- to 12-year-olds at a dental faculty showed a more than twofold higher failure rate for composite than for amalgam restorations after 7 years (15% vs 6%), mainly due to marginal caries.[8] Such a difference in longevity between composite and amalgam restorations is normally only found in studies that involved general practitioners.[2,73] The difference in longevity between dental faculty and general practitioners may be explained by the overall inferior quality of the restorations placed by general practitioners compared to those placed at universities or dental institutes. Another reason is the premature replacement of posterior resin restorations for reasons that contradict the scientific evidence. The most frequent reason for replacement given by general practitioners is caries adjacent to the restorative margin, which is also known as secondary or recurrent caries.[72] However, as most dentists confuse marginal staining with marginal caries, most restorations are replaced prematurely. Economic reasons may also explain the premature replacement of restorations. The frequent replacement of restorations, however, leads to larger cavities, and large restorations have a reduced longevity compared to small restorations.[106] Eventually, large restorations are replaced by crowns or extracted due to complications resulting from endodontic treatment.

As early as in the 1970s, composite resins were placed in posterior teeth. Those resins were macrofilled peroxide-initiated curing composites that were placed in bulk. In those days, the enamel was not etched with 36% phosphoric acid and the cavities were drilled in the same way as for amalgam restorations.[64,93] Mostly calcium hydroxide or glass-ionomer materials were placed as liners under the composite resin restorations. As there was only a limited number of shades available and as the peroxide-initiated curing properties led to a shift of color, the color match of those restorations was not good.

In the 1980s, enamel etching became integrated into the operative procedure and it became common practice to use an unfilled, hydrophobic, low-viscosity bonding material between resin and dental tissue. The resins were at first light cured with UV light units and later with halogen lamps. In addition to the macrofilled composites, microfilled composites appeared on the market. In the late 1980s, the first dentin bonding agents were developed, but these materials still required separate etching of enamel. This method was later replaced by the etch-and-rinse technique, which involves the simultaneous etching of both enamel and dentin. In 1999, the first self-etching enamel-dentin adhesive systems were released on the market. Since then, these systems – either one- or two-step – have gained popularity among dental practitioners because they shorten and simplify the operational procedures. Self-etching adhesive systems account for about 50% of the market share of all adhesive systems.[91]

Other strategies for streamlining the restorative procedures include the reduction of the number of composite layers applied, the so-called bulk-filling technique, as well as the reduction of curing time of the composite. Another step forward in reducing operational steps and time are self-adhering composite resins, which aim to incorporate adhesive properties into the resin composite and therefore eliminate the need for applying a separate adhesive system. The first such material, Vertise, a flowable self-adhering composite for small Class I and II restorations, was introduced on the market in 2010.[108]

The question arises as to how and to what extent the different tooth conditioning systems and composite resins affect the quality and longevity of posterior resin restorations. Four systematic reviews[13,16,46,62] and one meta-analysis[28] on Class II resin restorations have been published in the last 20 years. A short summary of the first systematic review has been published in two papers.[17,25] Two studies focused exclusively on direct composite resin restorations,[13,28] whereas the other studies included amalgam restorations and/or ceramic, gold restorations, and indirect composite restorations. However, all systematic reviews invariably included only those studies in which the restorative materials were applied in conjunction with the enamel etching technique. Furthermore, only one study[28] included a detailed analysis of various outcome variables, such as color match, marginal discoloration, etc, as well as the performance of two specific composite resin materials. The other systematic reviews only focused on the overall longevity of posterior restorations and did not pay attention to the specific reason for failures and other outcome variables. One review calculated a mean annual failure rate of direct composite resin restorations in Class II cavities of 2.3%, which was equal to that of amalgam restorations.[62]

Early studies involving operational procedures without etching and bonding were never systematically evaluated and compared to studies with enamel etching and enamel/dentin bonding. Furthermore, no systematic review which includes composite resins that are applied with self-etching adhesive resins has been published since 2003/2004.

The aim of this review was to systematically evaluate prospective clinical trials on multisurface resin composite restorations without restricting the search to the year of publication or the type of resin or adhesive system used.

The following factors in the clinical outcome were specifically evaluated: type of enamel/dentin conditioning; type of resin composite; operative technique: bevelling of enamel, absolute vs relative isolation, number of composite layers.

These factors were assessed by the following outcome criteria: time elapsed until replacement and reason for replacement (marginal caries, fracture of restoration, retention loss, endodontic treatment, etc); marginal integrity and marginal staining; color match and surface texture; anatomical shape; chipping and fracture; postoperative sensitivity.

The following hypotheses were examined:

- Etching of the enamel with phosphoric acid reduces the number of restorations that develop caries adjacent to restorations, marginal discoloration, defective marginal integrity, material chipping, and postoperative sensitivity compared to no etching and no bonding.
- Etching of the enamel with phosphoric acid reduces the number of restorations that show marginal discoloration and defective marginal integrity compared to self-etching systems.
- The type of isolation, bevelling of the enamel, or the number of layers does not influence the clinical outcome.
- Hybrid and microfilled composites show better color match than macrofilled composites.
- Hybrid composites demonstrate a better retention of their anatomical shape than microfilled composites and compomers.
- The type of composite resin used to fabricate the restoration does not influence the overall longevity.
- Compomer restorations have a reduced longevity compared to composite resin restorations.
- The longevity of composite resin restorations is similar to that of amalgam and does not depend on the type of resin composite.

MATERIALS AND METHODS

Selection of Clinical Trials on Class II Restorations

Prospective clinical studies on Class II restorations in permanent teeth were searched in SCOPUS (search period 1966-2011, search time April 2011). The search words were “Class II” or “posterior” and “clinical”. The inclusion criteria were as follows:

- Prospective clinical trial of direct Class II restorations or in Class I and Class II restorations in permanent teeth.
- Minimal duration of 2 years.
- Minimal sample size at last recall: 20 restorations per material group.
- The study had to report about the following outcome variables: marginal discoloration, marginal integrity, marginal caries, material fractures, color match, and anatomical shape. The variables “surface texture”, “surface staining”, “post-operative sensitivity” and “endodontic treatment” were optional variables.
- The study had to report on the applied materials and conditioning technique of hard tissues (etching of enamel with phosphoric acid yes/no, dentin/enamel bonding agent).
- The study had to report on the operative technique (bevelling of enamel, preparation, isolation technique, type of curing, layering technique).

If a study evaluated indirect and direct resin composite restorations, only the results of the direct resin restorations were included. Studies with experimental materials that were never launched on the market were not taken into account. The results of studies that evaluated minimally invasive procedures for proximal caries (slot preparations, cavity preparations with oscillating instruments, tunnel preparations, etc) or the repair of existing Class II composite resin restorations were also not included. There was no restriction with regard to the publication year.

With regard to the materials, studies with polyacid-modified resin composites (compomers) were also included because these materials do not differ very much from conventional resin composites. If a composite was placed in conjunction with a resin-modified glass-ionomer cement (placed on the gingival floor of Class II cavities) in what is known as the open-sandwich restoration technique, these studies were also included, as the major part of these restorations consists of conventional composite. However, studies with ion-releasing materials, known as “smart composites”, were excluded.

The restorative materials (RM) and adhesive systems (AS) were grouped as follows:

Restorative material

1 = macrofiller
2 = microfiller
3 = hybrid
4 = polyacid-modified resin composite (compomer)
5 = amalgam

Adhesive systems (AS)

1 = enamel etch-and-rinse (selective enamel etch-and-rinse + enamel bonding)
2 = enamel and dentin etch-and-rinse – 3 steps
3 = enamel and dentin etch-and-rinse – 2 steps
4 = self-etching – 2 steps
5 = self-etching – 1 step
6 = no etching + no bond

To further reduce the number of categories and to increase the statistical power, three adhesive classes (groups) were defined:

1 = etch-and-rinse (enamel etch-and-rinse and enamel and dentin etch-and-rinse)
2 = self-etching
3 = no etching + no bond

The following binary variables (two gradings) were considered, where the percentage of the category given in brackets will be analyzed below:

1. MD: marginal discoloration (not visible)
2. MI: marginal integrity (no clinically detectable margins with explorers)
3. CAR: caries adjacent to restorations (no caries)
4. F: material fracture (no chipping, no bulk fracture; alternatively with slight chipping or fracture)
5. AF: anatomical shape (good or very good)
6. C: color match (good or very good)
7. ST: surface texture (good or very good)
8. R: retention (retained restoration)
9. PHS: postoperative hypersensitivity (no)

For most of these variables (MD, MI, F, C, ST, and AF), the data were originally graded into three categories (1 = good or very good, corresponds to Ryge criterion "Alpha"; 2 = acceptable or repairable, corresponds to Ryge criteria "Beta" or "Charlie"; 3 = inacceptable and needs replacement, corresponds to Ryge criterion "Delta"), but since category 3 occurred only rarely, the variables were dichotomized for the analysis, as given above. However, category 3 was taken into account for some variables, particularly when defining and analyzing the longevity of a restoration and calculating the percentage of restorations still in function, referring to those restorations which did not need replacement for one (or more) of the following reasons: 1. CAR = caries adjacent to restorations (secondary caries); 2. F = material fracture; 3. R = loss or partial loss of restoration; 4. C = inacceptable color match; 5. MI = inacceptable marginal integrity; 6. AF = inacceptable anatomical shape.

Statistical Analysis

All the clinical outcomes could be expressed as percentages of restorations retaining a given property for the duration of the given experiment, for example, the percentage of restorations without a visible marginal discoloration, the percentage of restorations with a good or a very good anatomical form, or the percentage of restorations which did not need replacement, as defined above. To enable a comparison of the rate of deterioration among the various experiments, the percentages observed at the different points in time were divided by the percentage observed at baseline for those experiments where the latter was below 100% (which happened for some experiments with respect to the outcomes in the categories C, ST, AF, and PHS).

Let Y(t) be a percentage measured at time t (expressed in years). To model the rate of deterioration, we were looking for a model where Y(t) is a decreasing function of t ranging from Y(0) = 100% down to 0% for large values of t. A linear model of the form Y(t) = 100-beta x t would for example not be convenient, since it would have become negative for large values of t, which did not make sense in our context. We considered instead a deterioration model of the form Y = 100 x exp(-lambda x t^alpha) with positive values of alpha and lambda, which is equivalent to stating that Log(-Log Y/100) = beta+alpha x Log(t), with beta = Log(lambda).

To study how the deterioration process depends on a given factor of interest, we then considered the following statistical model for our empirical percentages Y(t):

Log(-Log(Y(t)/100)) = beta_j*X+alpha*Log(t)+study_effect+experiment_effect+random error.

In this model, beta_j is a fixed parameter characterizing the rate of deterioration for the level j of the factor of interest, such that the higher the parameter, the faster the deterioration (eg, a value of beta_j = -2 indicates a faster deterioration than a value of beta_j = -3). The parameter alpha characterizes the shape of the deterioration which does not depend on the factor of interest. A random experiment effect has been included to account for the obvious dependencies among the repeated percentages observed in the same experiment along time, while a random study effect has been included to account for the fact that the patients involved in different experiments from the same study were partly the same (split-mouth design).

In our model, the deterioration curve is thus assumed to be different from study to study and from experiment to experiment. Figures 1 to 14 show some of our fitted models as Y = 100*exp(-lambda_j*t^alpha), with lambda_j = exp(beta_j), which can be interpreted as a median deterioration curve for the level j of the factor of interest (estimated over all studies and experiments).

Such a linear mixed model could be fitted using the restricted maximum likelihood method implemented in the routine *lme* which can be found in the package *nlme* from the statistical software R. In this routine, it was also possible to weight each empirical percentage by the corresponding number of restorations (the denominator of the percentage). To test for the statistical significance of the factor of interest, a maximum likelihood ratio test was used, with the number of levels of the factor of interest minus one as number of degrees of freedom. P-values smaller than 0.05 were considered to be significant.

RESULTS

Study Search

The initial search revealed 373 clinical studies on Class II or posterior composite or compomer resin restorations. However, only 59 studies could be included in the review (see Appendix). The most frequent reasons for exclusion were (in descending order according to frequency): observation period less than 2 years, retrospective study, evaluation of restorations in primary teeth, pooling of data across different restorative materials, indirect composite restorations, specific outcome variables not related to the pre-defined ones,

Table 1 Number of experiments and sample size in relation to the tooth conditioning technique

Hard tissue conditioning class	Number of experiments	Number of restorations at baseline	Rubber-dam*		Bevelling of enamel*	
			yes	no	yes	no
Selective enamel etch-and-rinse + enamel bonding	41	3152	25	0	11	29
Enamel and dentin etch-and-rinse – 3 steps	15	1442	8	4	1	11
Enamel and dentin etch-and-rinse – 2 steps	34	1769	18	11	4	24
Self-etching – 2 steps	4	292	4	0	1	2
Self-etching – 1 step	9	394	6	3	1	8
No etching + no bond	13	709	6	6	0	13

*number of experiments

Table 2 Number of experiments and sample size in relation to the type of restorative material

Composite class	Number of experiments	Number of restorations at baseline	Rubber-dam*		Bevelling of enamel*	
			yes	no	yes	no
Amalgam	16	925	11	2	0	15
Macrofiller	18	1389	9	5	0	18
Microfiller	10	412	6	2	2	8
Hybrid	83	6155	50	14	16	57
Compomer	5	293	2	3	0	4

*number of experiments

specific preparation designs or other operational procedures (eg, repair), and application of an experimental material.

The results of 6 studies included in the evaluation were reported in more than one publication (usually in two). One material (Occlusin, ICI Dental; Macclesfield, UK) was tested in a multicenter trial. The various centers reported on their results separately. However, in this review, only the results of the publication that summed the results of all individual trials were included.

Structure of Included Studies

The 59 studies included contain 132 in vivo experiments with 58 different composites, 38 different adhesive systems, and 63 different combinations of adhesives/composites. The type of adhesive and composite/restorative material is listed in the table of the Appendix. Eighty-four percent of the experiments had an observation period of up to 5 years. In 55 experiments, only Class II cavities had been filled with composite resin, and in 75 experiments, both Class I and Class II cavities had been treated. Only in two experiments were the results published separately for Class I and Class II restorations. For 84 experiments, data on the ratio of premolar vs molar restorations were reported; the mean ratio was 46% (± 24) with a range from 0% to 100%, which means that all teeth treated were either premolars or molars. In Tables 1 and 2, the frequency of studies as well as the number of restorations at baseline in relation to the hard tissue conditioning method and the different groups of restorative materials are listed.

Out of the 132 experiments, the occlusal (and sometimes proximal) enamel was bevelled in 18 experiments, and absolute isolation (rubber-dam) was applied in 78 experiments (Tables 1 and 2). For 8 experiments, no data were published for enamel bevelling, and for 26 experiments, there was no indication as to what type of isolation was applied (Tables 1 and 2).

In 10 experiments a so-called packable resin composite was used, in one experiment a so-called Ormocer composite, and in 3 experiments a resin-modified glass-ionomer cement was placed on the gingival floor of the proximal box in conjunction with a hybrid composite resin. Due to the low number of experiments, these experiments were added to the category of "hybrid composite".

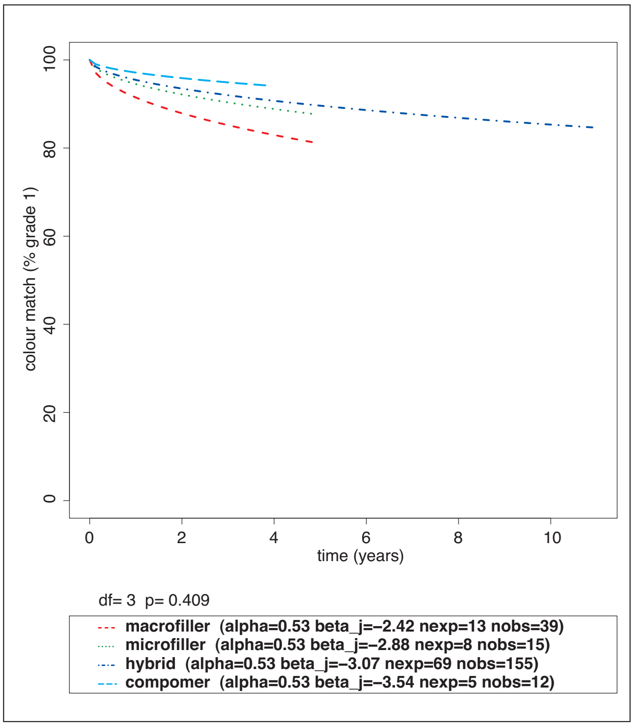

Fig 1 Estimated median percentage of restorations across the studies and experiments with good or very good color match in relation to the type of restorative material and to the observation time.

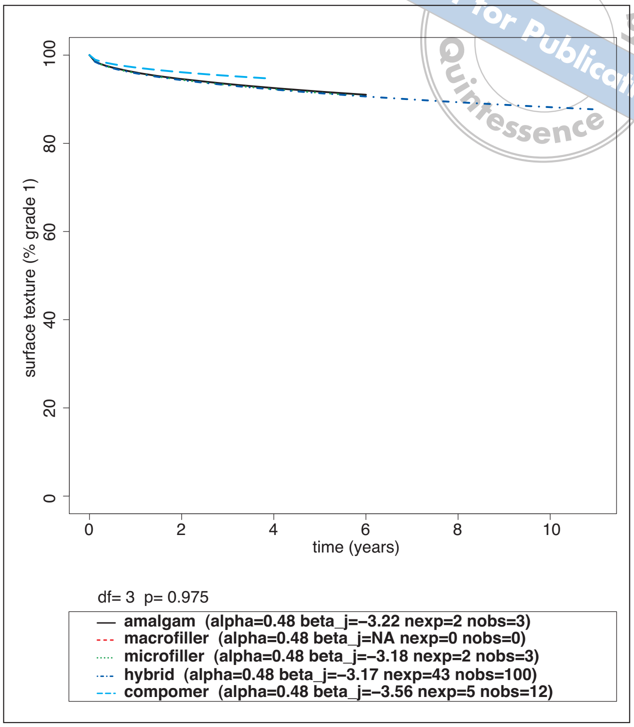

Fig 2 Estimated median percentage of restorations across the studies and experiments with good or very good surface texture in relation to the type of restorative material and to the observation time.

Outcome Variables

The curves presented in the figures below refer to the estimated median percentage of deterioration (across studies and experiments) for the binary outcomes in relation to time and to various other factors of interest. Curves are plotted for the longest observation time of the corresponding factor levels. The parameters alpha and beta_j, as well as the number of experiments (n_{exp}) and the number of observed percentages (n_{obs}) were also provided for each factor level, together with a p-value from a maximum likelihood ratio test. As usual in a statistical study, the result might not be statistically significant despite large differences among the curves, due to a high between-studies variability and/or to the small number of studies involved. On the other hand, statistical significance might be achieved despite a seemingly small difference among the curves in case of a low between-studies variability. The length of the curves corresponds to the observation time of the investigated materials or hard tissue conditioning systems.

The decrease of restorations with good or very good color match was dependent on the type of composite material. Macrofilled composites showed the worst deterioration and hybrid composites and compomers the least (Fig 1). However, the difference was not statistically significant.

As far as surface texture is concerned, there was no statistically significant difference between the different types of materials (Fig 2). However, for studies which included more than 50% molars compared to premolars and for those that included more than 50% Class II in relation to Class I restorations, the statistical analysis revealed significantly fewer restorations with good surface texture compared to those studies with fewer molar restorations ($p = 0.04$) and Class II restorations ($p = 0.004$).

The loss of anatomical form was material dependent. Restorations with macrofillers and compomer showed a significantly greater increase of restorations with suboptimal anatomical form than those that were restored with other restorative materials (Fig 3). Restorations with amalgam showed the least decrease. For most of the other materials, the decrease was statistically significant, with the exception of the microfilled composites (post-hoc test amalgam vs macrofiller $p < 0.001$, amalgam vs hybrid filler $p = 0.021$, amalgam vs compomer $p = 0.014$). Macrofilled composites showed a statistically significantly higher decrease of anatomical wear than hybrid and microfilled composites (post-hoc test $p < 0.001$). There was no difference between microfillers and hybrid composites (post-hoc test $p = 0.467$). The variables "bevelling of enamel", "rubber-dam", "ratio of Class I/Class II restorations" or "ratio of premolar/molar restorations" did not influence the results.

Restorations with compomers suffered more chipping (repairable fracture) than restorations with other materials; however, the difference was not statistically significant (post-hoc test $p = 0.144$) (Fig 4). Median frequencies of chipping were estimated at 9% vs 3% after 4 years for

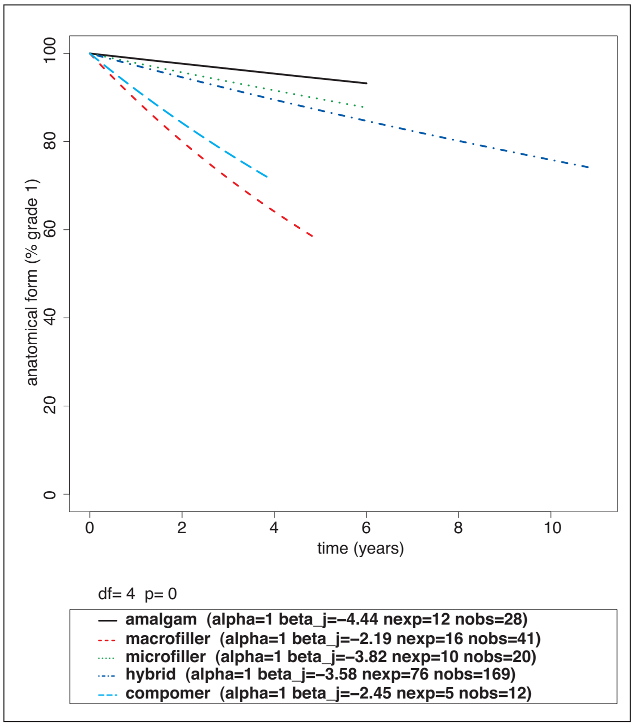

Fig 3 Estimated median percentage of restorations across the studies and experiments with adequate anatomical form (shape) in relation to the type of restorative material and to the observation time.

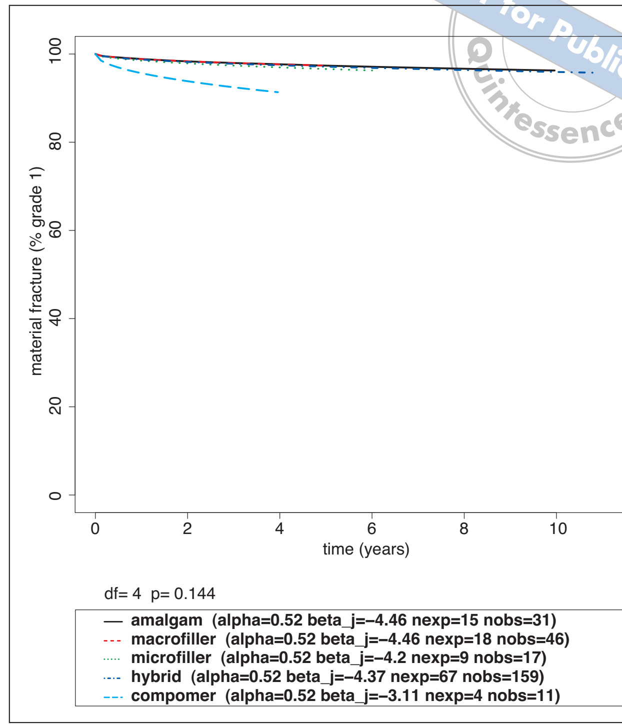

Fig 4 Estimated median percentage of restorations across the studies and experiments without material chipping/fracture to the restoration in relation to the type of restorative material.

compomer restorations vs restorations made with the other materials. As far as material fractures that led to the replacement of restorations are concerned, there was also no statistically significant difference between the materials (Fig 5). There were, however, significantly more material fractures in those resin restorations which were applied without rubber-dam (see also Fig 14). The variables “bevelling of enamel”, “ratio of Class I/Class II restorations” or “ratio of premolar/molar restorations” did not significantly influence the results.

The frequency of caries adjacent to restorations (CAR) was low in most studies, with a median prevalence of about 3% after 10 years (Fig 6). The occurrence was not dependent on the type of material (Fig 6) or the type of tooth conditioning (Fig 7).

The decrease of restorations with no marginal staining was dependent on the tooth conditioning technique. When enamel was not acid etched with phosphoric acid and when no adhesive system was applied, the decline was rapid, and after 4 years already 58% of the restorations had marginal staining. In contrast, marginal discoloration was found in only 11% of the restorations when the enamel was phosphoric-acid etched and in 21% when a self-etching system was used (Figs 8 and 9). The difference was statistically significant for phosphoric-acid etched enamel vs no etching (post-hoc test $p = 0.001$), enamel etching vs self-etching (post-hoc test $p = 0.036$), as well as for self-etching vs no etching (post-hoc test $p = 0.037$). The variables “bevelling of enamel”, “rubber-dam”, “ratio of Class I/Class II restorations” or “ratio of premolar/molar restorations” did not significantly influence the results.

For the outcome variable marginal integrity, an average of 27% of the no etch/no bond restorations had detectable margins after 4 years, 32% for the self-etching restorations and 13% for the etch-and-rinse restorations (Fig 10). The difference was statistically significant only for enamel etch-and-rinse vs self-etching restorations (post-hoc test $p = 0.001$) but not for etch-and-rinse vs no etch/no bond. The variables “bevelling of enamel”, “rubber-dam”, “ratio of Class I/Class II restorations” or “ratio of premolar/molar restorations” did not significantly influence the results.

Post-operative sensitivity was infrequent and there was no significant difference between restorations placed with etch-and-rinse adhesives and those placed with self-etching adhesives (Fig 11).

The reasons for restoration replacement were predominantly bulk fractures and caries at the restorative margins. A very small number of restorations were replaced due to retention loss, inacceptable color match, inacceptable marginal integrity, endodontic treatment, or cusp fracture. The replacement rate for restorations with compomer was higher compared to the other materials (Fig 12), but the difference was not statistically significant. As far as the dental-tissue conditioning method is concerned (Fig 13), restorations that were placed with self-etching adhesive systems were statistically more often replaced than those that were placed with the

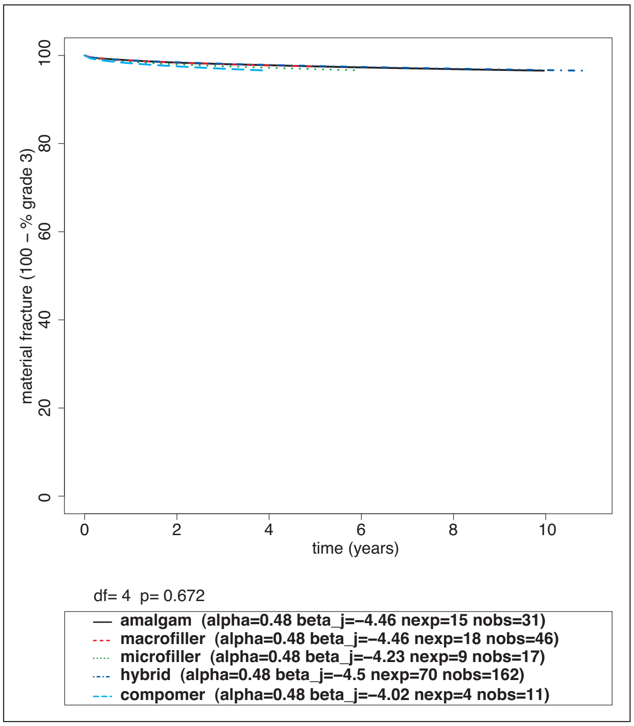

Fig 5 Estimated median percentage of restorations across the studies and experiments without bulk fractures in relation to the type of restorative material and to the observation time.

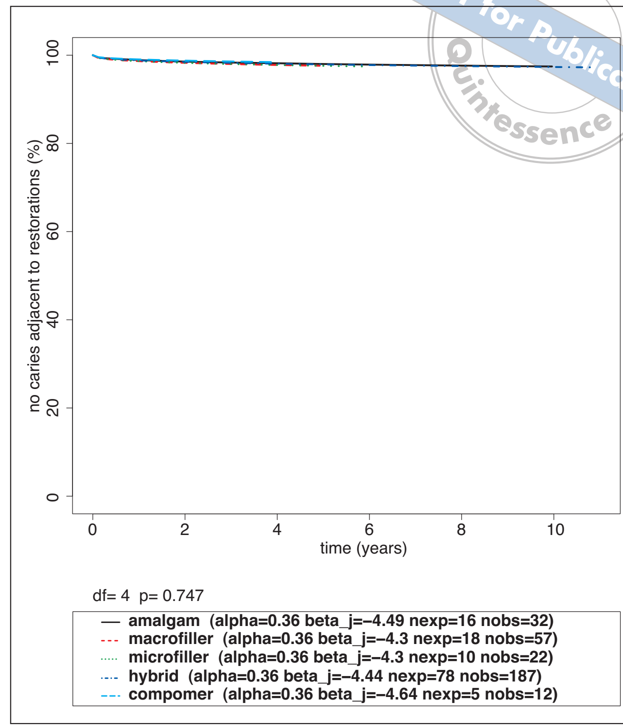

Fig 6 Estimated median percentage of restorations across the studies and experiments without caries adjacent to the restoration in relation to the type of restorative material.

etch-and-rinse technique applied to enamel and dentin or to enamel separately (post-hoc test p = 0.037). The median success rate of composite restorations (excluding compomer) was about 92% after 10 years and was similar to that of amalgam restorations (94%). Restorations that were placed with rubber-dam showed a statistically significantly higher longevity than restorations that were placed without rubber-dam (p = 0.003). This is probably mainly due to the fact that restorations that were placed with rubber-dam had statistically significantly fewer material fractures than restorations that were placed without rubber-dam (Fig 14).

In Table 3, the clinical performance of the three major conditioning methods in relation to certain outcome variables is summarized. In Table 4, the same is done for the 5 different groups of restorative materials.

For seven composite resin materials, data were available from at least 4 studies (Table 5). A separate analysis was performed for these materials. As far as the overall longevity is concerned, there was no statistically significant difference between the 7 materials. However, there were differences according to certain clinical parameters, such as color match, surface texture, anatomical form, material fractures, and marginal integrity. The macrofilled materials Adaptic and Concise as well as the hybrid material P30 showed a significantly worse performance for these parameters compared to Prisma TPH, Tetric Ceram, SureFil, and Ful-Fil (Table 5).

DISCUSSION

Meta-analyses are considered a valid method to combine the results from clinical trials that were selected according to predefined criteria and to extract data in order to draw conclusions about the efficacy of a therapeutic intervention – in this case, the longevity of artificial materials and their operative technique to restore defective teeth in the posterior region. However, there is no consensus on the applied statistical method for a meta-analysis. In the present study, we considered a linear mixed model with random effects to account for both the heterogeneity between the studies and the repeated observations across time within an experiment to be the most appropriate approach.

This is the first meta-analysis that evaluated the effects of the hard tissue conditioning method and the effects of the composite material on specified outcome variables, including the longevity of restorations. The review included studies that tested composite resins placed in cavities without enamel etching and enamel bonding; these studies comprised more than 700 Class II restorations at baseline. It was surprising that 7 studies were found in the literature of the 1970s and early 1980s that applied composite resins in the way described before. The quality of the study design and reporting of the results were adequate and could be compared with studies that were published 10 to 20 years later. In 6 of the 7 studies,

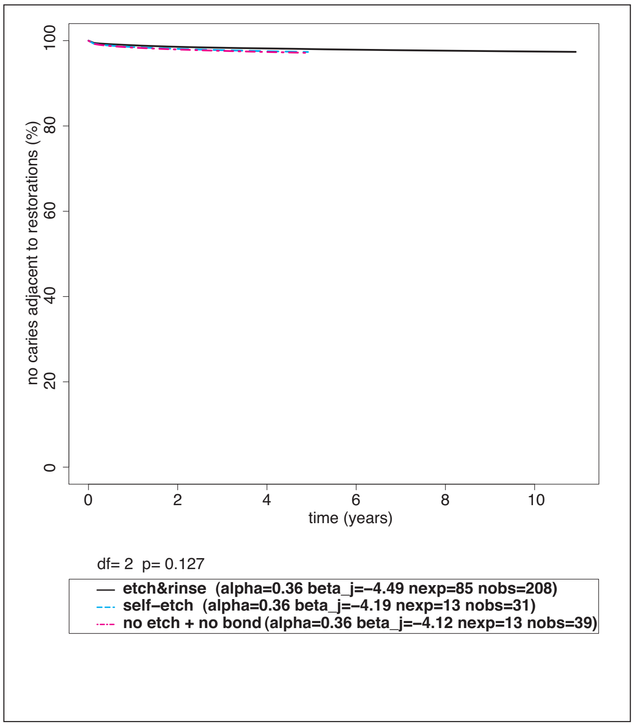

Fig 7 Estimated median percentage of restorations across the studies and experiments without caries adjacent to the restoration in relation to the type of adhesive system.

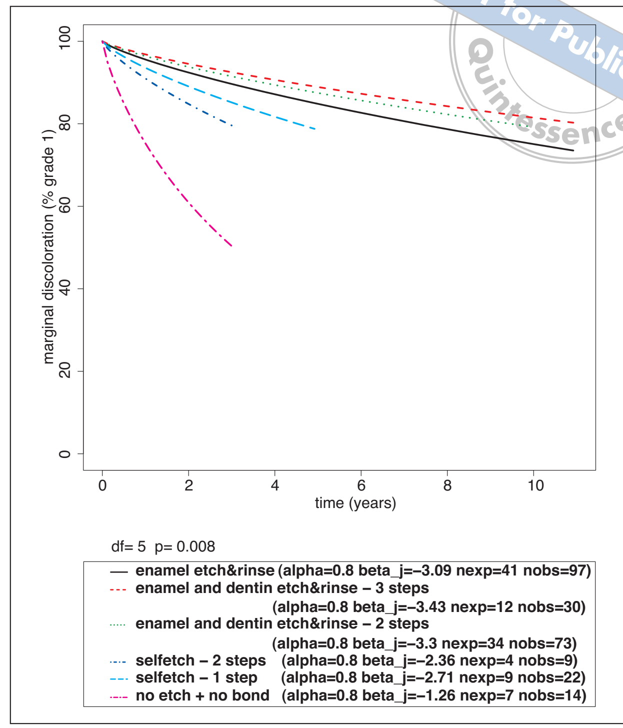

Fig 8 Estimated median percentage of restorations across the studies and experiments without marginal staining in relation to the adhesive technique and adhesive system and to the observation time.

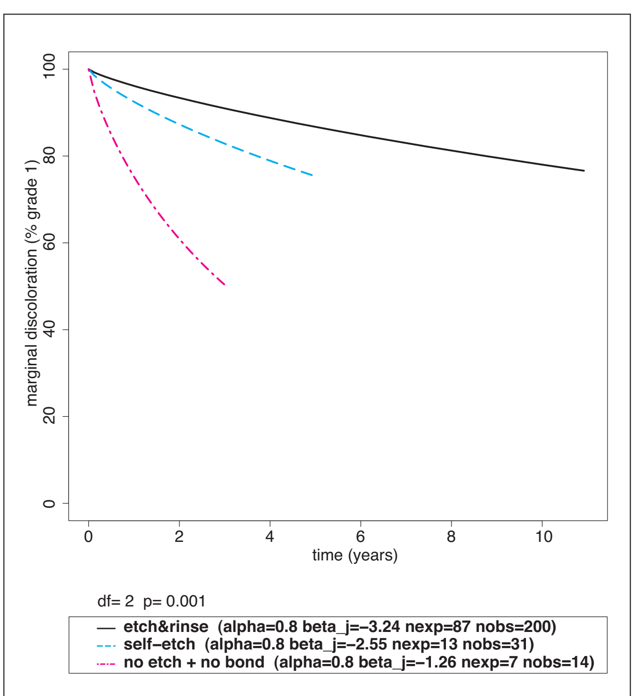

Fig 9 Estimated median percentage of restorations across the studies and experiments without marginal staining in relation to the adhesive technique and adhesive system and to the observation time.

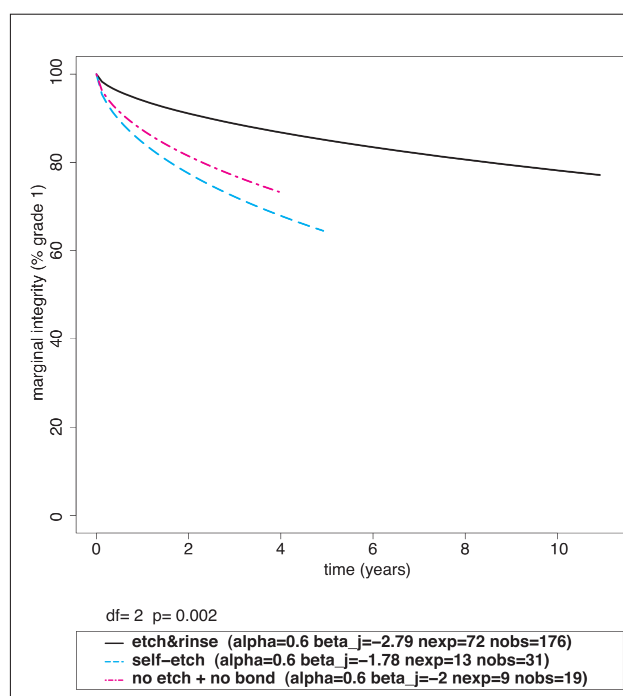

Fig 10 Estimated median percentage of restorations across the studies and experiments without detectable margins in relation to the adhesive technique and to the observation time.

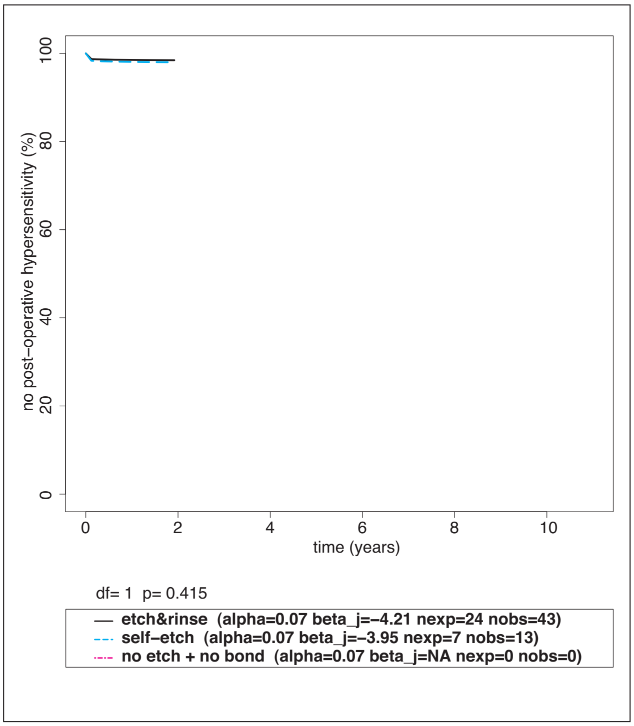

Fig 11 Estimated median percentage of restorations across the studies and experiments without post-operative sensitivity in relation to the adhesive technique and to the observation time.

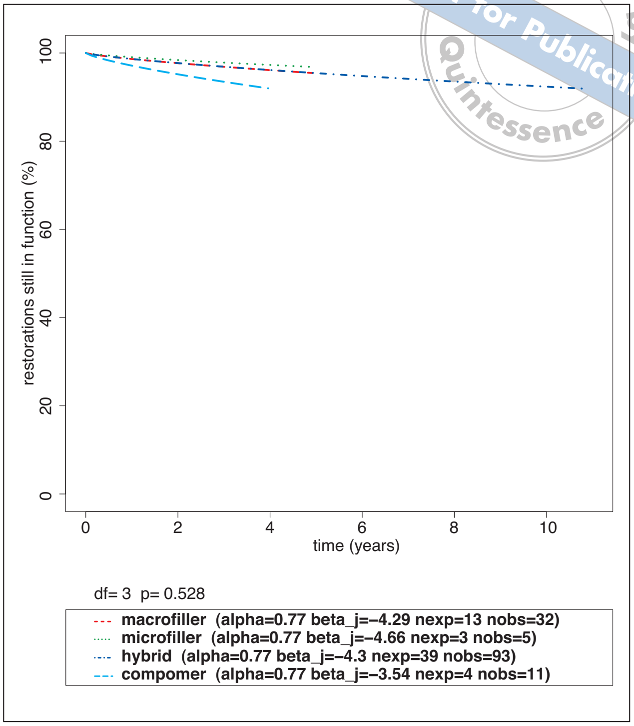

Fig 12 Estimated median percentage of restorations across the studies and experiments that were not replaced in relation to the type of restorative material.

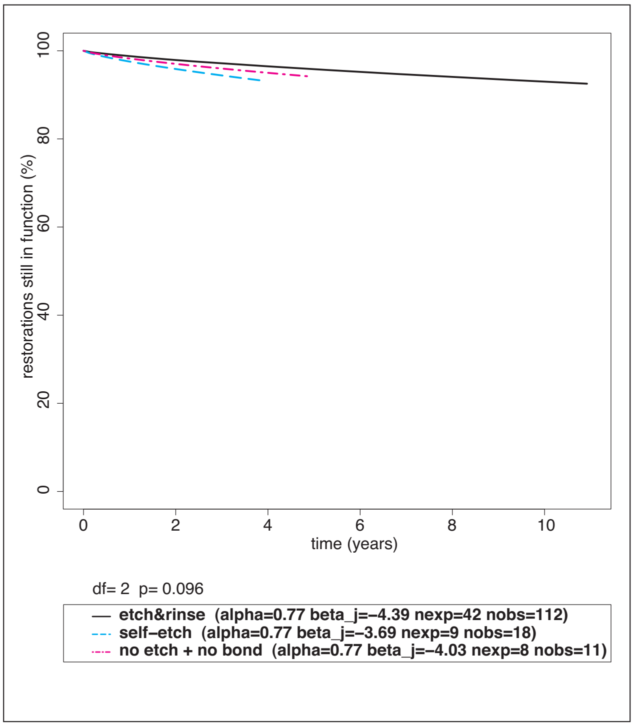

Fig 13 Estimated median percentage of restorations across the studies and experiments that were not replaced in relation to the adhesive technique and to the observation time.

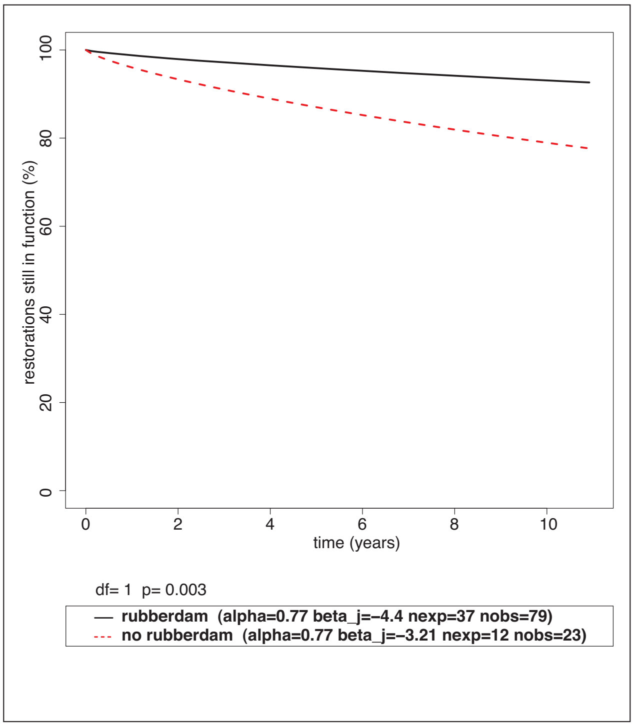

Fig 14 Estimated median percentage of restorations across the studies and experiments that were not replaced in relation to the application of rubber-dam.

Table 3 Clinical performance of composite resin restorations in relation to the tooth conditioning method

Hard tissue conditioning class	Number of experiments	Marginal staining	Marginal integrity	Caries adjacent to restorations	Material fracture
Etch-and-rinse	16	+	+	+	+
Self-etching	18	-	+/-	+	+
No etching + no bond	10	–	+/-	+/-	+

++ = very good, + = good, +/- acceptable, - = bad, – = very bad.

Table 4 Clinical performance of posterior restorations in relation to the restorative material

Composite resin	Number of experiments	Color match	Surface texture	Anatomical form (shape)	Material fracture
Amalgam	16		+	++	+
Macrofiller	18	-	+	-	+
Microfiller	10	+	+	+	+
Hybrid	83	+	+	+	+
Compomer	5	+	+	-	-

++ = very good, + = good, +/- acceptable, - = bad, – = very bad.

Table 5 Clinical performance of 7 composite resin materials for which data were present from at least 4 studies

Composite resin	Number of experiments	Color match	Surface texture	Anatomical form (shape)	Material fracture	Caries at margin
Adaptic	10	-	+	-	+	+
Concise	4	-	+	-	+	+
Tetric Ceram	6	++	+	+	+	+
Prisma TPH	4	+	+	++	+	+
SureFil	4	++	+	+	+	+
P30	5	-	–	+	+	+
Ful-Fil	7	+	-	+	+	+

++ = very good, + = good, +/- acceptable, - = bad, – = very bad.

the control material was amalgam and the allocation of test and control material was carried out in a split-mouth design. Five of these 7 studies included more than 1 composite resin and 1 study (n = 66) had an observation time of 5 years.

The best overall performance (good color match, small amount of fractures) was achieved with restorations based on hybrid and microfilled composites; the overall longevity was similar to that of amalgam restorations. The performance of so-called packable composite materials (SureFil, Alert, Prodigy Condensable, Tetric Ceram HB, Solitaire) was similar to that of hybrid composites, which is in line with the review by Brunthaler et al.[13] Macrofilled composites exhibited a significantly less favourable color match and a significantly higher loss of anatomical form. Compomer restorations suffered more material fractures than any other type of material. The systematic review by Brunthaler et al[13] also revealed a higher failure rate for conventional (macrofilled) than hybrid composites.

As far as specific resin materials are concerned, the two macrofilled materials Adaptic and Concise as well as the hybrid material P30 showed a significantly worse performance compared to the other hybrid materials Tetric Ceram, Prisma TPH, SureFil, and Ful-Fil. Of these materials, only SureFil and Prisma TPH are still available on the market. Interestingly, the meta-analysis by El Mowafy et al[28] which did a separate analysis for Ful-Fil in 1994, resulted in similar numbers with regard to the anatomical form and marginal adaptation but not with regard to the color match.

Some of the clinical phenomena can be explained by material-inherent properties. The rapid deterioration of the color match in the macrofilled peroxide-initiated curing materials (eg, Concise and Adaptic) is related first to the initiators of the peroxide-initiated curing mechanism (eg, amines), which are not very color stable, and second to the higher amount of monomers compared to hybrid and microfilled composites.[19,102] The increased loss of anatomical form is related to the size of the filler: the larger the diameter of the main filler, the higher the wear rate of the composite.[43] However, the flexural strength of the self-curing macrofilled composite was comparable to that of contemporary composites (> 100 MPa).[48,87] and explains the similar chipping and fracture frequency compared to hybrid composites. If the flexural strength is below 80 MPa, which is the minimum value required by the ISO standard for posterior restorations,[49] Class II restorations exhibit more chipping and bulk fractures. This was shown for the packable material Solitaire, which was put on the market in 1998. At the time, its flexural strength was only 57 MPa.[1] In prospective clinical trials with this material, more than 20% of the Class II restorations exhibited fractures in the area of the marginal ridge and margins after only 2 years[31,55] (appendix: study no. 33). The manufacturer altered the material, which then possessed a flexural strength of 120 MPa.[1] The subsequent clinical studies showed that Class II restorations with Solitaire 2 exhibited much fewer restoration fractures after 2 years.[14,35] Compomers (eg, Dyract, Dyract AP) have a flexural strength that is lower (< 80 MPa) than that of contemporary resin composites (eg, Z100);[27] other physical properties, such as compressive strength and microhardness, are also significantly lower.[27] In one laboratory study, the flexural strength of Dyract AP dropped to 40 MPa after storage for 6 months in artificial saliva.[79] The low flexural strength of Dyract and Dyract AP explains the higher chipping and fracture rate of these materials.

Marginal discoloration and detectable margins are the only clinical measurable signs for the evaluation of the marginal seal of direct restorations. As 80% of the margins and 100% of the visible margin of Class II restorations is located in enamel, the bonding to enamel is crucial for the prevention of marginal discoloration and for a good seal. Enamel etching with 36% phosphoric acid is the best method to establish a microretentive pattern that allows favorable bonding to cut enamel: the bond strength to cut enamel conditioned with a phosphoric-acid etching system is superior to cut enamel conditioned with a self-etching system.[21] Besides the conditioning method, the orientation of the enamel prisms is important. A study showed that the microtensile bond strength was higher if the enamel was cut parallel rather than perpendicular to the prism orientation.[47] The bevelling of the enamel margin prior to conditioning, however, did not significantly influence the occurrence of marginal discoloration in the present meta-analysis.

Based on the mean annual failure rate of 2.3% of Class II restorations published by Manhart et al,[62] the failure rate after 10 years would amount to about 23%. This could not be confirmed in the present systematic review, as the median failure rate after 10 years was about 8% for resin composites (without compomers). This discrepancy may be explained by three facts: (1) Manhart et al[62] assumed a linear progession of the failure or success rate, which is not true and has not been confirmed by the present review; (2) Manhart et al did not analyze the data with a linear mixed model; (3) Manhart et al included some studies with higher failure rates which, however, did not fulfil the inclusion criteria of the present review.

Another interesting and unexpected result of this review was that the overall longevity of multisurface composite resin restorations did not significantly depend on the type of enamel and dentin conditioning system, at least not over a period of 5 years. If, however, the enamel was not etched with either phosphoric acid or a self-etching primer, there was a rapid increase in the number of restorations with marginal staining. As far as the marginal integrity is concerned, the difference between restorations that were placed with the etch-and-rinse technique was less pronounced compared to those restorations that were placed with the no etch/no bond technique; the difference between these two techniques was still statistically significant, while the difference between the no-etching and self-etching methods was not statistically different.

The low number of restorations with caries at the margins compared to those that showed marginal staining confirms the conclusions based on other studies, ie, marginal staining as such is not indicative of marginal caries, nor is it an indication of a defective margin.[69] In cross-sectional investigations performed in general practices, marginal caries was usually cited as the most frequent reason for replacing a restoration, irrespective of the restorative material used and the type of preparation and location in the mouth.[18,34,70,72,74-76,82,110,114] In these studies, data were collected from general practitioners by questionnaires and they were asked to give the reasons for the replacement of direct restorations. The frequency of replaced restorations reported by the general practitioners was about 50%; 40% of these restorations were replaced due to caries at the margins, which means that in general practices, about 20% of restorations are replaced due to suspected caries at the margins. However, the present systematic review, which involved only prospective clinical trials, showed a low incidence of both replaced restorations and restorations that were replaced due to caries adjacent to restorations. The variability across studies was small and the frequency was independent of the type of composite material. Two reasons for these contradictory results are possible: (1) the quality of restorations fabricated by general practitioners is considerably worse compared to the quality achieved at dental faculties, and (2) general practitioners often replace restorations unnecessarily.

The question is whether restorations whose quality does not comply with the quality standards established by academia are directly correlated with reduced longevity. According to the systematic review by Brunthaler et al,[13] the type of operator (general practitioner, university dentist) had no significant influence on the longevity of direct posterior resin restorations evaluated in prospective clinical trials. This result suggests that most practitioners replace restorations unnecessarily, which may be explained either by economic reasons and/or ignorance about evidence-based reasons for the replacement of restorations, which also explains the great variability among dentists with regard to diagnosis and treatment options.[4,39] As far as caries at the restorative margins is concerned, it is evident from a number of investigations that general practitioners often relate marginal staining to caries at the margins and replace the restorations because of suspected caries.[96]

In restorative and operative dentistry, most clinical studies published in peer-reviewed journals were carried out and are still carried out at dental faculties. Few studies have been conducted with the help of general practitioners. Only recently has practice-based research gained importance,[23] and longitudinal clinical trials have shown that the repair of defective restorations is equivalent to or even better than the replacement of restorations.[40]

The low frequency of caries adjacent to the restorative margins confirms the results of an earlier review on different composite restorations with an observation period between 3 and 17 years.[13] In most of the studies, the earliest time at which marginal caries appeared was 2 years after the placement of the restoration. Material-dependent differences in the frequency of caries at the margins were observed in studies involving different materials.[18,90] However, it is doubtful that these results were directly related to the materials. The incidence rate of secondary caries was higher in test subjects with higher caries activity.[52] The same applies to the studies which were conducted in general practices.[16] One study in which 912 amalgam and 1955 composite restorations were placed between 1990 and 1997 by two general practitioners and re-examined in 2002 showed a prevalence rate of marginal caries of 5% to 6% – irrespective of the restoration material used.[80] As far as the location of caries at the restorative margin of posterior restorations is concerned, a clinical trial revealed that caries is about 8 times more frequent at the gingival floor than at the occlusal margin, of Class II composite restorations and about 10 times more frequent at the gingival floor of amalgam restorations compared to the occlusal margin.[71] This can be explained by the fact that the biofilm is easily removed from occlusal and axio-proximal margins by tooth brushing, saliva, and mastication. However, the same does not apply to the cervico-proximal margins, where the biofilm can grow almost unchecked.

One drawback to making the above conclusion is the relatively short duration of the clinical trials which did not etch the enamel or apply a bonding agent (between 2 and 5 years). It is possible that with an observation period of more than 5 years, the number of restorations with caries at the restorative margins might have been higher. In one study, the authors wrote that the number of restorations showing caries at the margins of or beneath the restoration significantly increased over time, but this was not substantiated by the data concerning the materials Concise and Adaptic. With these two resin materials, the number of restorations that developed caries was not significantly different from the number of amalgam restorations with caries. However, in all these studies, some sort of liner was used, either calcium hydroxide or glass-ionomer cement; this may have reduced the risk for caries and also postoperative hypersensitivity. Restorations with another resin material (Epoxydent), which was carved with hand instruments during the setting process, developed caries adjacent to restorations very rapidly. As this was the only trial that included this type of material, it was excluded from the systematic review. The sculptability of this material should have given it amalgam-like handling properties, but instead it resulted in wide marginal openings which promoted the development of caries. The low incidence of caries at the restorative margins of those restorations whose enamel was not etched indicates that a gap per se is not a prerequisite for the formation of caries. As the volumetric shrinkage of the peroxide-initiated curing materials Adaptic and Concise were in the range of 2%,[38] which is similar to that of contemporary composites, the width of the resulting gap may be in a range that did not promote caries beyond an incidence of 3% after 5 years.

The duration time of the clinical trials was short, not only for the trials without enamel etching and bonding, but also for the trials with self-etching adhesive systems. The results of long-term clinical trials are only available for the enamel and dentin etch-and-rinse technique as well as the selective enamel etch-and-rinse technique. There was a tendency for restorations with self-etching primers to have a higher prevalence of marginal staining than restorations with phosphoric-acid enamel etching. Although there was no significant difference between etch-and-rinse systems and self-etching as far as marginal caries is concerned, general practitioners are advised to use etch-and-rinse systems, as the occurrence of marginal staining tends to be lower with this technique. Marginal discoloration is usually linked to irregularities in the margin, such as gaps, fractures, etc. Therefore, it is more appropriate to clinically evaluate marginal fractures, gaps, etc than marginal adaptation, as considerable differences exist between the assessments of marginal adaptation by different evaluators.[99] Besides the properties of the margins, factors specific to the patient, such as eating habits and oral hygiene regimes, most probably play an important part. In a prospective study on inlays cemented with the adhesive technique, the restorations were clinically examined every year over a period of 8 years. At the same time, the marginal quality was evaluated on sub-samples by means of replicas.[41] The examinations revealed that the existence of marginal irregularities closely correlated with the clinical diagnosis of “marginal discoloration”. The appearance of marginal imperfections preceded clinically visible marginal discolorations by about 1 to 2 years.

Nevertheless, it is still unclear in which state (fractured margins, marginal gap of which width, etc) the margin is more susceptible to discoloration.

A clinical study in which composite restorations in posterior teeth were annually examined over a period of 10 years showed that the percentage of restorations with marginal discoloration increased linearly over a period of 0 to 5 years, with an annual increase of 6% to 10%. After the 5th year, there was only a slight increase.[36] In some studies which examined various composite materials, differences in the frequency of marginal discoloration dependending on the material were recorded.[18,61,90,100] Besides possible effects of the composite material itself, clinical results can be influenced by the specific operative technique used as well as the operator or factors related to the patient. However, the factor which most strongly influences marginal discoloration is certainly the type of enamel conditioning. Among the composite restorations placed without any enamel etching or bonding, the frequency of marginal discoloration increased very rapidly, with about 40% of restorations showing stained margins already after 2 years. In contrast, if the enamel was etched with phosphoric acid, the mean number of restorations with stained margins was only about 10% after 3 years, increasing to about 20% after 10 years. Composite restorations that are placed with self-etching adhesive systems showed a somewhat higher frequency of stained margins compared to those that were placed with enamel etching.

As the prevalence of marginal discoloration is about 6 to 7 times higher than that of marginal caries and as the existence of marginal gaps or imperfections is usually necessary for the development of marginal discoloration, this is an indication that (1) marginal gaps per se are not responsible for causing marginal caries and (2) marginal staining is not indicative of marginal caries. Nevertheless, practitioners should try to reduce the risk of marginal staining. This can only be achieved by etching the enamel with 37% phosphoric acid. This operative procedure contributes to less premature replacement of restorations, as general practitioners often associate marginal staining with caries at the margins.[96]

Studies have shown that large Class II restorations exhibit more stained margins than small restorations and they appear more often along axio-proximal margins than along occlusal margins.[111] The present study revealed that bevelling of the coronal (and proximal) enamel did not reduce the number of restorations with marginal staining. A meta-analysis on cervical restorations (Class V) came to the same conclusion:[42] bevelling of the coronal enamel did not reduce the occurrence of marginal staining. However, it must be mentioned that in the present review the enamel was bevelled in only 18 of the 116 experiments (= 16%) involving composite resins.

The application in bulk vs layering technique had no significant influence on any of the clinical outcome parameters. However, the application of rubber-dam (absolute isolation) compared to cotton rolls and suction (relative isolation) significantly reduced the occurrence of material fractures and therefore promoted the overall success of the restorations. This is in contrast to the previous systematic review on Class II restorations by Brunthaler et al[13] – a study which found that rubber-dam application did not influence the longevity of posterior resin restorations. The reason for the increased frequency of material chipping can only be speculative. It is possible that without rubber-dam, the polymerization of the composite may be inferior compared to that with rubber-dam due to moisture, and the material is therefore more prone to material chipping. No laboratory study has been found in the literature that has evaluated the flexural strength of composite materials that were submitted to moisture or artificial saliva during polymerization. Another possible explanation could be that moisture impairs a good bond between different layers of composite and/or to the conditioned dental tissue, thus compromising the stability of the entire restoration.

The number of Class II restorations relative to that of Class I restorations or the number of molar restorations relative to the number of premolar restorations did not influence the median longevity rate of the restorations in the studies and was not significant for any of the other variables except for surface texture. A lower number of restorations with good surface texture was observed when more molars than premolars were restored and when more Class II than Class I cavities were present. This may be explained by the size of the restoration. Molar restorations have a larger surface that can disintegrate than do premolar restorations and so do Class II compared to Class I restorations. One review found significantly more failures for Class II than Class I resin restorations,[13] but no difference between premolar and molar restorations.

CONCLUSION

For clinicians and general practitioners, the implications of the present meta-analysis are as follows:

1. Adhesive system: To achieve best results, the dentist should prefer an adhesive system which includes enamel conditioning with 37% phosphoric acid. This reduces the occurrence of marginal discoloration, which in turn may reduce the temptation to prematurely replace restorations due to the confusion between stained margins and caries at the margin.
2. Material: Hybrid and microfiller composites were equal to amalgam (except for color match). Macrofilled composites and compomers demonstrated more shortcomings (wear, fractures).
3. Operative procedure: The additional bevelling of the enamel did not result in reduced marginal discoloration. If the clinical situation allows it, absolute isolation with rubber-dam is preferable.

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Clinical relevance: The results of the meta-analysis on posterior composite restorations showed that under university-clinic conditions, only a few resin restorations needed replacement after 10 years of clinical service and that longevity did not differ from that of amalgam restorations. The best clinical performance can be achieved if hybrid composites are applied with rubber-dam in conjunction with etch-and-rinse adhesive systems. However, longevity of composite resin restorations was not dependent on the type of adhesive system.

APPENDIX

First author	Reference no.	Publication year	Year when study started	Black class	Premolar: molar ratio (%)	Class I: Class II ratio (%)	Bevelling	Rubber-dam
Phillips	88	1973	1969	Class II	-	0	no	yes
Phillips	88	1973	1969	Class II	-	0	no	yes
Eames	26	1974	1969	Class I	-	100	no	yes
Eames	26	1974	1969	Class II	-	0	no	yes
Eames	26	1974	1969	Class I	-	100	no	yes
Eames	26	1974	1969	Class II	-	0	no	yes
Osborne	81	1973	1970	Class II	-	0	no	yes
Osborne	81	1973	1970	Class II	-	0	no	yes
Leinfelder	56	1975	1972	Class I + Class II	-	77	no	yes
Leinfelder	56	1975	1972	Class I + Class II	-	72	no	yes
Leinfelder	56	1975	1972	Class I + Class II	-	48	no	yes
Morris	78	1977	1973	Class II	-	0	no	-
Morris	78	1977	1973	Class II	-	0	no	-
Roulet	93, 94	1980	1976	Class II	-	0	no	no
Roulet	93, 94	1980	1976	Class II	-	0	no	no
Roulet	93, 94	1980	1976	Class II	-	0	no	no
Mannerberg	64-66	1983	1977	Class II	-	0	no	no
Mannerberg	64-66	1983	1977	Class II	-	0	no	no
Mannerberg	64-66	1983	1977	Class II	-	0	no	no
Mannerberg	64-66	1983	1977	Class II	-	0	no	no
Gibson	37	1982	1979	Class I		100	no	yes
Gibson	37	1982	1979	Class I		100	no	yes
Hendriks	45	1986	1982	Class I + Class II	-	3	no	yes
Hendriks	45	1986	1982	Class I + Class II	-	30	no	yes
Hendriks	45	1986	1982	Class I + Class II	-	9	no	yes
Hendriks	45	1986	1982	Class I + Class II	-	9	no	yes
Hendriks	45	1986	1982	Class I + Class II	-	3	no	yes
Hendriks	45	1986	1982	Class I + Class II	-	26	no	yes
Sturdevant	98	1988	1982	Class I + Class II	40	43	no	-
Barnes	6	1991	1982	Class I + Class II	30	76	yes	yes
Richardson	92	1987	1982	Class I + Class II	-	70	yes	yes
Richardson	92	1987	1982	Class I + Class II	-	77	yes	yes
Boksman	10	1986	1982	Class I + Class II	50	44	no	-
Wilson	112	1991	1984	Class I + Class II	50	24	3	-
Wilson	112	1991	1984	Class I + Class II	50	24	3	-
Prati	89	1988	1984	Class I + Class II	60	60	no	yes
Prati	89	1988	1984	Class I + Class II	62	52	no	yes
Prati	89	1988	1984	Class I + Class II	54	53	no	yes
Cunningham	20	1990	1985	Class I + Class II	-	17	no	-

Curing of composite	Adhesive system	Adhesive class	Restorative material	Material class	Observation period (years)	Number of restorations baseline
peroxide-initiated curing		no etch, no bond	Adaptic	macrofiller	3	109
		no etch, no bond	Amalgam	amalgam	3	109
peroxide-initiated curing		no etch, no bond	Adaptic	macrofiller	4	35
peroxide-initiated curing		no etch, no bond	Adaptic	macrofiller	3	43
peroxide-initiated curing		no etch, no bond	Amalgam	amalgam	4	36
peroxide-initiated curing		no etch, no bond	Amalgam	amalgam	3	43
peroxide-initiated curing		no etch, no bond	Concise	Macrofiller	2	103
		no etch, no bond	Amalgam	amalgam	2	103
peroxide-initiated curing		no etch, no bond	Adaptic	macrofiller	2	79
peroxide-initiated curing		no etch, no bond	Concise	macrofiller	2	86
		no etch, no bond	Amalgam	amalgam	2	141
peroxide-initiated curing		no etch, no bond	Adaptic	macrofiller	3	77
		no etch, no bond	Amalgam	amalgam	3	77
peroxide-initiated curing		no etch, no bond	Adaptic	macrofiller	3	41
peroxide-initiated curing		no etch, no bond	Concise	macrofiller	3	41
		no etch, no bond	Amalgam	amalgam	3	41
peroxide-initiated curing		no etch, no bond	Adaptic	macrofiller	5	22
peroxide-initiated curing		no etch, no bond	Compocap	macrofiller	5	23
peroxide-initiated curing		no etch, no bond	Concise	macrofiller	5	21
peroxide-initiated curing		no etch, no bond	Isocap	microfiller	3	29
peroxide-initiated curing		enamel etch+enamel bond	Adaptic	macrofiller	2	84
		enamel etch+enamel bond	Amalgam	amalgam	2	84
peroxide-initiated curing		enamel etch+enamel bond	Adaptic	macrofiller	3	37
peroxide-initiated curing		enamel etch+enamel bond	Adaptic	macrofiller	3	23
		no etch, no bond	Amalgam	amalgam	3	22
peroxide-initiated curing		enamel etch+enamel bond	Profile	hybrid	3	34
peroxide-initiated curing		enamel etch+enamel bond	Estic	microfiller	3	31
peroxide-initiated curing		enamel etch+enamel bond	Estic	microfiller	3	27
light curing		enamel etch+enamel bond	Ful-Fil	hybrid	4	65
light curing	Prisma Bond	enamel etch+enamel bond	Ful-Fil	hybrid	7	33
light curing		enamel etch+enamel bond	Ful-Fil	hybrid	4	116
peroxide-initiated curing		enamel etch+enamel bond	P-10	hybrid	4	121
light curing	Prisma Bond	enamel etch+enamel bond	Ful-Fil	hybrid	3	98
light curing		enamel etch+enamel bond	Occlusin	hybrid	4	958
-			Amalgam	amalgam	3	232
peroxide-initiated curing	Concise enamel bond	enamel etch+enamel bond	Silar	microfiller	3	45
peroxide-initiated curing	Concise enamel bond	enamel etch+enamel bond	P-10	hybrid	3	48
			Amalgam	amalgam	3	55
peroxide-initiated curing	Clearfil Bonding	enamel/dentin etch-and-rinse -2 steps	Clearfil Posterior	hybrid	10	121

First author	Reference no.	Publication year	Year when study started	Black class	Premolar: molar ratio (%)	Class I: Class II ratio (%)	Bevelling	Rubber-dam
Cunningham	20	1990	1985	Class I + Class II	-	10	no	-
Cunningham	20	1990	1985	Class I + Class II	-	17	yes	-
Cunningham	20	1990	1985	Class I + Class II	-	19	no	-
Brunson	12	1989	1985	Class I + Class II	47	44	yes	yes
Wilder	109	1991	1985	Class I + Class II	24	72	no	-
Wilder	109	1991	1985	Class I + Class II	32	83	no	-
Wilder	109	1991	1985	Class I + Class II	58	58	no	-
Wilder	109	1991	1985	Class I + Class II	44	76	no	-
Collins	18	1998	1986	Class I + Class II	10	90	no	yes
Collins	18	1998	1986	Class I + Class II	10	90	no	yes
Gängler	36	2001	1987	Class I + Class II	44	59	yes	yes
Dietschi	24	1990	1987	Class I + Class II	-	21	yes	yes
Dietschi	24	1990	1987	Class I + Class II	-	10	yes	yes
Dietschi	24	1990	1987	Class I + Class II	-	20	yes	yes
Dietschi	24	1990	1987	Class I + Class II	-	14	yes	yes
van Dijken	103	2000	1988	Class II	56	0	no	yes
Johnson	50	1992	1988	Class I + Class II	21	54	yes	yes
Johnson	50	1992	1988	Class I + Class II	28	58	yes	yes
Johnson	50	1992	1988	Class I + Class II	20	75	no	yes
Freilich	33	1992	1988	Class I + Class II	-	-	no	-
Freilich	33	1992	1988	Class I + Class II	-	-	no	-
Rasmussen	90	1995	1989	Class II	100	0	no	-
Rasmussen	90	1995	1989	Class II	100	0	no	-
Rasmussen	90	1995	1989	Class II	100	0	no	-
Rasmussen	90	1995	1989	Class II	100	0	no	-
Rasmussen	90	1995	1989	Class II	76	0	no	-
Rasmussen	90	1995	1989	Class II	100	0	no	-
Pallesen	83	2003	1991	Class II	63	0	no	no
Pallesen	83	2003	1991	Class II	63	0	no	no
Helbig	44	1998	1992	Class I + Class II	63	19	yes	yes
Busato	15	2001	1993	Class I + Class II	45	79	3	yes
Busato	15	2001	1993	Class I + Class II	48	69	3	yes
Busato	15	2001	1993	Class I + Class II	47	75	3	yes
Perry	86	1997	1994	Class II	22	0	no	yes
Wassell	107	2000	1994	Class II	25	0	no	yes
Türkün	100	2003	1995	Class I + Class II	22	73	no	-

Curing of composite (ref. no.)	Adhesive system	Adhesive class	Restorative material	Material class	Observation period (years)	Number of restorations baseline
light curing	Occlusin Bond	enamel etch+enamel bond	Occlusin	hybrid	10	122
light curing	Scotchbond 1	enamel/dentin etch-and-rinse-2 steps	P-30	hybrid	10	119
peroxide-initiated curing			Amalgam	amalgam	10	243
peroxide-initiated curing	-	enamel etch-and-rinse	P-10	hybrid	3	89
light curing	-	enamel etch-and-rinse	Estlilux	hybrid	5	29
light curing	-	enamel etch-and-rinse	Nuva-Fil	macrofiller	5	41
light curing	-	enamel etch-and-rinse	Nuva-Fil PA	macrofiller	5	26
light curing	-	enamel etch-and-rinse	Uvio-Fil	macrofiller	5	34
light curing	-	enamel etch-and-rinse	Heliomolar	microfiller	6	83
-	-	no etch, no bond	Amalgam	amalgam	6	82
light curing	Universalbond	enamel etch-and-rinse	Visio-Molar radi-opaque	hybrid	6	194
light curing	-	enamel etch-and-rinse	P-30	hybrid	2	19
light curing	-	enamel etch-and-rinse	Ful-Fil	hybrid	2	20
light curing	-	enamel etch-and-rinse	Heliomolar	microfiller	2	20
light curing	-	enamel etch-and-rinse	Estilux post.	hybrid	2	21
light curing	-	enamel etch-and-rinse	Ful-Fil	hybrid	11	34
light curing	-	enamel etch-and-rinse	Bisfil-P	hybrid	3	48
light curing	Scotchbond L/C	enamel etch-and-rinse	P-30	hybrid	3	40
peroxide-initiated curing	-		Amalgam	amalgam	3	40
light curing	-	enamel etch-and-rinse	Adaptic II	hybrid	3	46
light curing	-	enamel etch-and-rinse	Marathon	hybrid	3	32
light curing	-	enamel etch-and-rinse	Occlusin	hybrid	5	47
light curing	-	enamel etch-and-rinse	P-30	hybrid	5	49
light curing	-	enamel etch-and-rinse	Ful-Fil	hybrid	5	62
light curing	-	enamel etch-and-rinse	Profile	hybrid	5	32
light curing	-	enamel etch-and-rinse	Heliomolar	microfiller	5	30
light curing	-	enamel etch-and-rinse	Distalite	microfiller	5	27
light curing	Gluma/Clearfil Bond	enamel/dentin etch-and-rinse 3 steps	Brilliant	hybrid	11	28
light curing	Gluma/Clearfil Bond	enamel/dentin etch-and-rinse 3 steps	Estilux post.	hybrid	11	28
light curing	Scotchbond2	enamel/dentin etch-and-rinse 3 steps	P-50	microfiller	5	27
light curing	Scotchbond Multi-purpose	enamel/dentin etch-and-rinse 3 steps	Z100	hybrid	6	34
light curing	Scotchbond Multi-purpose	enamel/dentin etch-and-rinse 3 steps	Tetric	hybrid	6	34
light curing	Scotchbond Multi-purpose	enamel/dentin etch-and-rinse 3 steps	Charisma	hybrid	6	35
light curing	ProBond	enamel/dentin etch-and-rinse 2 steps	Prisma TPH	hybrid	2	50
light curing	Duo Cure Bond	enamel etch-and-rinse	Brilliant	hybrid	5	100
light curing	-	enamel/dentin etch-and-rinse 2 steps	Z100	hybrid	5	40

First author	Reference no.	Publication year	Year when study started	Black class	Premolar: molar ratio (%)	Class I: Class II ratio (%)	Bevelling	Rubber-dam
Türkün	100	2003	1995	Class I + Class II	22	73	no	-
Türkün	100	2003	1995	Class I + Class II	22	73	no	-
Baratieri	5	2001	1996	Class I + Class II	34	35	no	yes
Perry	85	2000	1997	Class II	0	0	no	-
Lindberg	57	2007	1997	Class II	45	0	no	yes
Lindberg	57	2007	1997	Class II	45	0	no	yes
Ernst	31	2001	1997	Class I + Class II	49	28	no	no
Krämer	54	2006	1998	Class I + Class II	56	30	no	no
Krämer	54	2006	1998	Class I + Class II	56	30	no	no
Wucher	113	2002	1998	Class II	43	0	no	no
Wucher	113	2002	1998	Class II	43	0	no	no
Wucher	113	2002	1998	Class II	43	0	no	no
Luo	60	2002	1999	Class I + Class II	43	45	3	yes
Lopes	58	2003	2000	Class I + Class II	34	45	no	yes
Lopes	58	2003	2000	Class I + Class II	45	48	no	yes
Fagundes	32	2007	2001	Class I + Class II	51	55	3	yes
Fagundes	32	2007	2001	Class I + Class II	55	36	3	yes
Sachdeo	95	2004	2001	Class II	0	0	no	no
Sachdeo	95	2004	2001	Class II	0	0	no	no
Sachdeo	95	2004	2001	Class II	0	0	no	no
Türkün	101	2005	2001	Class I + Class II	38	29	no	no
Lundin	59	2004	2001	Class I + Class II	54	18	-	yes
Wilson	111	2006	2002	Class I + Class II	10	33	no	yes
Sarrett	97	2006	2002	Class II	57	0	no	yes
van Dijken	104	2009	2003	Class II	-	0	no	no
van Dijken	104	2009	2003	Class II	-	0	no	no
Bottenberg	11	2009	2003	Class II	59	0	yes	yes
Bottenberg	11	2009	2003	Class II	58	0	yes	yes
Bottenberg	11	2009	2003	Class II	68	0	yes	yes
Ernst	30	2006	2003	Class II	72	0	no	yes
Ernst	30	2006	2003	Class II	66	0	no	yes
Gallo	35	2005	2003	Class I + Class II	-	40	no	yes
Gallo	35	2005	2003	Class I + Class II	-	40	no	yes
Bekes	7	2007	2004	Class I + Class II	40	27	yes	yes

Curing of composite	Adhesive system	Adhesive class	Restorative material	Material class	Observation period (years)	Number of restorations baseline
light curing	-	enamel/dentin etch-and-rinse 2 steps	Clearfil Posterior	hybrid	5	40
light curing	-	enamel/dentin etch-and-rinse 2 steps	Prisma TPH	hybrid	5	40
light curing	Scotchbond Multi-purpose	enamel/dentin etch-and-rinse 3 steps	Z100	hybrid	4	726
light curing	Prime&Bond 2.1	enamel/dentin etch-and-rinse 2 steps	SureFil	hybrid	2	24
light curing	Prime&Bond 2.1	enamel/dentin etch-and-rinse 2 steps	Dyract/Prisma TPH	compomer	9	75
light curing	Prime&Bond 2.1	total etch-2 steps	Prisma TPH	hybrid	9	75
light curing	Solid Bond	enamel/dentin etch-and-rinse 2 steps	Solitaire	hybrid	3	250
light curing	OSB	enamel/dentin etch-and-rinse 2 steps	Hytac	compomer	4	38
light curing	Prime&Bond 2.1	enamel/dentin etch-and-rinse 2 steps	Dyract AP/TPH Spectrum	compomer	4	33
light curing	Prime&Bond 2.1	enamel/dentin etch-and-rinse 2 steps	Prisma TPH	hybrid	3	23
light curing	Prime&Bond 2.1	enamel/dentin etch-and-rinse 2 steps	Dyract	compomer	3	23
light curing	Prime&Bond 2.1	enamel/dentin etch-and-rinse 2 steps	Dyract AP	compomer	3	23
light curing	NRC/Prime&Bond NT	self-etch 2 steps	Dyract AP	compomer	2	91
light curing	OptiBond Solo	enamel/dentin etch-and-rinse 2 steps	Prodigy Condens-able	hybrid	2	38
light curing	Etch&Prime 3.0	self-etch 1 step	Definite	hybrid	2	40
light curing	Bond1	enamel/dentin etch-and-rinse 2 steps	SureFil	hybrid	5	33
light curing	Prime&Bond NT	enamel/dentin etch-and-rinse 2 steps	Alert	hybrid	5	33
	-		Amalgam	amalgam	2	45
light curing	Syntac Sprint	enamel/dentin etch-and-rinse 2 steps	Tetric Ceram	hybrid	2	35
light curing	Prime&Bond 2.1	enamel/dentin etch-and-rinse 2 steps	Dyract AP/TPH Spectrum	compomer	2	53
light curing	Prime&Bond NT	enamel/dentin etch-and-rinse 2 steps	SureFil	hybrid	3	55
light curing	Syntac Sprint	enamel/dentin etch-and-rinse 2 steps	Tetric Ceram	hybrid	2	148
light curing	FL Primer/Bond	self-etch 2 steps	Beautiful	compomer	3	108
light curing	OptiBond Solo	enamel/dentin etch-and-rinse 2 steps	Prodigy Condens-able	hybrid	3	53
light curing	Excite	enamel/dentin etch-and-rinse 2 steps	InTen-S	hybrid	5	53
light curing	OptiBond Solo	enamel/dentin etch-and-rinse 2 steps	Point 4	hybrid	5	53
light curing	Admira Bond	enamel/dentin etch-and-rinse 2 steps	Admira	hybrid	5	44
light curing	Etch&Prime 3.0	self-etch 1 step	Definite	hybrid	5	43
light curing	Syntac Sprint	enamel/dentin etch-and-rinse 2 steps	Tetric Ceram	hybrid	5	41
light curing	Scotchbond 1	enamel/dentin etch-and-rinse 2 steps	Filtek Supreme	hybrid	2	56
light curing	Scotchbond 1	enamel/dentin etch-and-rinse 2 steps	Tetric Ceram	hybrid	2	56
light curing	Comfort Bond	enamel/dentin etch-and-rinse 2 steps	Solitaire2	hybrid	2	31
light curing	Solid Bond	enamel/dentin etch-and-rinse 2 steps	Solitaire2	hybrid	2	31
light curing	AdheSE	self-etch 2 steps	Tetric Ceram HB	hybrid	2	50

First author	Reference no.	Publication year	Year when study started	Black class	Premolar: molar ratio (%)	Class I: Class II ratio (%)	Bevelling	Rubber-dam
Bekes	7	2007	2004	Class I + Class II	40	27	yes	yes
Krämer	53	2011	2004	Class II	66	0	no	yes
Krämer	53	2001	2004	Class II	66	0	no	yes
Demarco	22	2007	2004	Class II	47	0	-	yes
van Dijken	105	2011	2005	Class II	37	0	no	no
van Dijken	105	2011	2005	Class II	37	0	no	no
Manhart	63	2010	2005	Class I + Class II	-	19	no	yes
Manhart	63	2010	2005	Class I + Class II	-	13	no	yes
Perdigão	84	2009	2006	Class I + Class II	45	24	no	yes
Perdigão	84	2009	2006	Class I + Class II	43	23	no	yes
Perdigão	84	2009	2006	Class I + Class II	45	23	no	yes
Perdigão	84	2009	2006	Class I + Class II	42	23	no	yes
Ermis	29	2009	2006	Class II	64	0	no	yes
Ermis	29	2009	2006	Class II	70	0	no	yes
Arhun	3	2010	2007	Class I + Class II	51	27	no	no
Arhun	3	2010	2007	Class I + Class II	51	37	no	no
Kiremitci	51	2009	2007	Class II	57	0	no	no
Monteiro	77	2010	2007	Class II	100	0	-	-
Monteiro	77	2010	2007	Class II	100	0	-	-

Curing of composite (ref. no.)	Adhesive system	Adhesive class	Restorative material	Material class	Observation period (years)	Number of restorations baseline
light curing	Excite	enamel/dentin etch-and-rinse 2 steps	Tetric Ceram HB	hybrid	2	50
light curing	Solobond M	enamel/dentin etch-and-rinse 2 steps	Grandio	hybrid	6	36
light curing	Syntac	enamel/dentin etch-and-rinse 3 steps steps	Tetric Ceram	hybrid	6	32
light curing	Single Bond	enamel/dentin etch-and-rinse 2 steps	P60	hybrid	2	109
light curing	Xeno III	self-etch 1 step	Ceram X	microfiller	4	93
light curing	Excite	enamel/dentin etch-and-rinse 2 steps	Ceram X	hybrid	4	72
light curing	Xeno III	self-etch 1 step	QuixFil	hybrid	4	46
light curing	Syntac	enamel/dentin etch-and-rinse 3 steps steps	Tetric Ceram	hybrid	4	50
light curing	Clearfil S3 Bond	self-etch 1 step	Filtek Supreme	hybrid	2	29
light curing	iBond	self-etch 1 step	Filtek Supreme	hybrid	2	30
light curing	Prompt L-Pop	self-etch 1 step	Filtek Supreme	hybrid	2	31
light curing	One Step Plus	etch-and-rinse 2 steps	Filtek Supreme	hybrid	2	31
light curing	Single Bond	total etch-2 steps	Z250	hybrid	2	44
light curing	Clearfil SE	self-etch 2 steps	Z250	hybrid	2	43
light curing	Futurabond	Self-etch 1 step	Grandio	hybrid	2	41
light curing	Xeno III	Self-etch 1 step	QuixFil	hybrid	2	41
light curing	Solid Bond	enamel/dentin etch-and-rinse 3 steps	P60	hybrid	6	47
light curing	Prime&Bond NT	enamel/dentin etch-and-rinse 2 steps	Ceram X	hybrid	2	34
light curing	Prime&Bond NT	enamel/dentin etch-and-rinse 2 steps	SureFil	hybrid	2	34